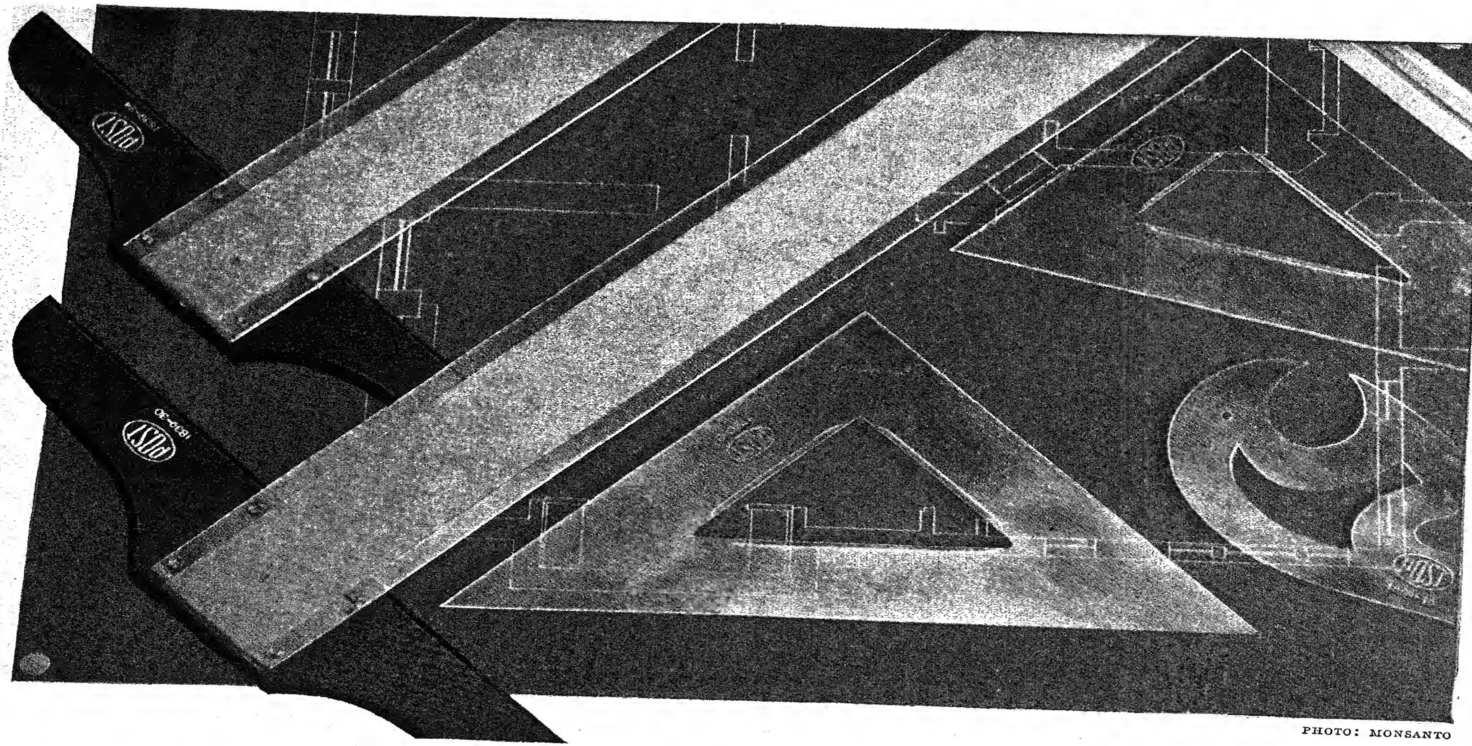

PHOTO: MONSANTO

TOOLS USED IN THE FIELD OF APPLIED MATHEMATICS

These drawing instruments made of plastics are notable for their clarity and freedom from shrinkage and distortion.

THE BOOK OF

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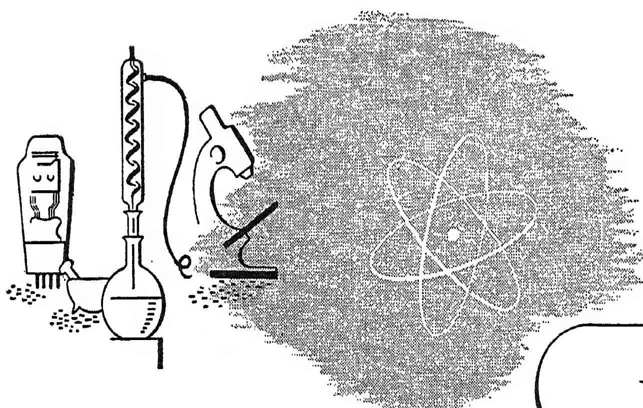

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CONTENTS OF VOLUME VIII

RIVERS AS SCULPTORS

Rivers Above and Below Ground; Their Cutting and Carrying Powers; What They Destroy and What They Build

MOUNTAINS LEVELED TO MAKE NEW LANDS

WE have already shown that the waters that are under the earth give birth to springs, and that springs often give birth to rivers. But the waters that are under the earth are often full-grown rivers in themselves, and run, as

Alph the sacred river ran,
Through caverns measureless to man
Down to a sunless sea.

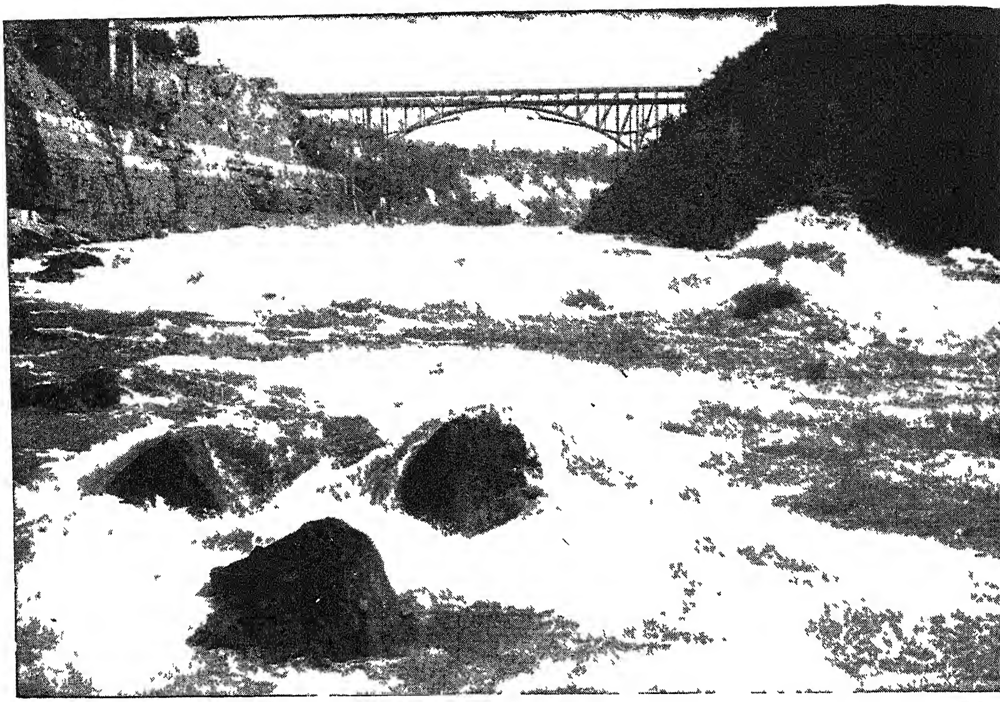
This we might guess, for inexhaustible springs discharging millions of gallons a day must have rivers of water somewhere behind. But it is not merely a matter of guessing, for, from all time, subterranean rivers have been known, and from all time they have appealed to the curiosity and imagination of mankind.

As might be expected, they are most plentiful in limestone regions. Sometimes they gush out of the ground far inland; sometimes they are unseen until they fall into the sea from the face of some cliff; sometimes they enter the sea below sea level. Near old Fort Klamath, in southern Oregon, a large river springs right out of the ground; and from the base of Kilimanjaro, in Central Africa, more than one subterranean river rises. In Syria, we have the Nahr-el-Kelb issuing full-grown from mighty caverns. In Greece we have the Stymphalus, which plunges underground and does not emerge again for twenty miles or more.

One of the most beautiful and most famous of subterranean streams is the Sorgues of Vaucluse in France. In flood, its stream flows at the rate of about thirty cubic yards a second, and quite fills its cavernous exit, but when its waters are low it is possible to penetrate underground and inspect "the vast basin in which the blue waters of the subterranean stream spread out before they leap into the open air". The river runs for at least ten miles underground, and on its exit it divides into numerous channels, which irrigate more than 77 square miles of Provence.

The region of the Carniolan and Istrian Alps, on the eastern shores of the Adriatic, is famous for its caves and underground rivers. It is to this region that the Timavo, described by Virgil, belongs. From this region, too, several subterranean rivers flow into the Adriatic below low-water level, and one, the Trebintchitza, can be easily seen entering the sea about a yard below the salt-water surface. Here, too, near Adelsberg, we find the Poik, which pursues a subterranean course for five or six miles under a mountain.

The calcareous shores of the United States are penetrated by various subterranean rivers, some of which undoubtedly flow underground for great distances. Off Florida, in 1857, there was a remarkable discharge of fresh water into the sea. Reclus states that "muddy and yellowish water furrowed the straits, and myriads of dead fish floated on the surface and accumulated on the shores. Even in the open sea the saltness diminished by one-half, and in some places the fishermen drew their drinking-water from its surface as if from a well. It is affirmed by all those who witnessed this remarkable inundation of the subterranean river that, during more than a month, it discharged at least as much water as the Mississippi itself, and spread over all the strait, thirty-one miles wide, which separates Key West from Florida."



THE WHITE FOAMING RAPIDS BELOW NIAGARA FALLS

It might seem at first sight that the work of rivers is small compared with the work of the sea. The sea is dramatic in its wrath; it wrecks armadas, it tears down cliffs, it inundates cities, it corrodes away continents; it is deeper in places than the Himalayas are high, and it is vaster in its area than all the dry land of the world; while rivers, as a rule, are merely silver threads running across islands and continents, brawling a little as they tumble down hill, but placid in their meandering course across the plains And yet the work of rivers is far mightier than that of the sea, and often is dramatic enough

The destructive power of rivers is proved by the load they carry, visible and invisible; the invisible is matter in solution, the visible is material in suspension and coarser material shoved along the bottom, the last averaging perhaps 10 per cent of the solids not in solution. This complex triple load in any river varies of course with the force of the river and the nature of the bed and drainage area. With regard to soluble matter, the Moll, a mountain stream in Carinthia (Jugo-Slavia), flowing from a glacier over crystalline schists, contains only 2.61 parts of mineral matter in 100,000 parts of water; and the Scottish Dee, flowing over rocks almost entirely composed of silicates, contains only 3 12 parts in 100,000 The Delaware contains 6 5, the Hudson 14, the Mississippi 17 and the Thames over 27 parts per 100,000. An average for American and European rivers gives about 19 parts of solutes in 100,000, of which calcium carbonate is about 9 parts

These figures are too abstract in themselves to give much idea of the amounts of solids borne away by rivers; and interesting attempts have been made to depict more correctly the destruction wrought by rivers. Bischof estimated that the Rhine carries annually into the sea enough calcium carbonate to make three hundred and thirty-two thousand millions of oyster-shells of the usual size. It has been calculated that every year the Thames removes 140 tons of the same mineral from every square mile of the limestone areas of its basin. The Hudson, not a large river, carries to the sea every day over 1200 tons of dissolved solids, and the Mississippi more than 309,000 tons.

With regard to solids not in solution, the Elbe has been calculated to carry away mineral matter at the rate of 48 tons per square mile yearly; the Rhône, at Avignon, 232 tons per square mile, the Mississippi, 120 tons The Ganges and Brahmaputra bring down annually into the Bay of Bengal about 40,000,000 cubic feet of sediment. The material from the Ganges alone, if built up into a pyramid with a base of one square mile, would be 516 feet high "But the Ganges is beaten by the Mississippi, for its pyramid would rise to 804 feet; while the Hoang-ho works yet harder to fill up the Yellow Sea, for the pyramid formed of its detritus would tower up to 2190 feet" — half as high as the greater peaks of the Catskills.

All this material, dissolved and suspended, is stolen or eroded by rivers from their drainage area. As rivers erode at different rates, they lower their basins at different rates. Sir Archibald Geikie gives the accompanying interesting table showing the fraction of cubic foot of rock by which the area of drainage of six great river basins is annually lowered.

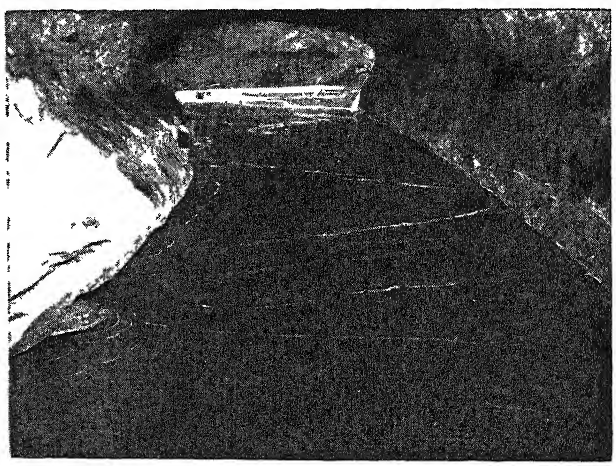
Otherwise expressed, the Mississippi erodes a foot in 6000 years, the upper Ganges in 823 years, the Hoang-ho in 1464 years, and the Rhône, Danube and Po in 1528, 6846 and 729 years respectively At the rate of erosion of the Mississippi, North America would be worn down to sea level in about 4,500,000 years; and at the rate of erosion of the Ganges, Asia would be reduced to sea level in a little more than 930,000 years; while if Europe were eroded at the rate of the erosion of the Po, it would be washed away down to sea level in less than 500,000 years.

Name of river	Area of basin in square miles	Annual discharge of sediment in cubic feet	Fraction of foot of rock by which the area of drainage is lowered in one year
Mississippi .	1,147,000	7,468,694,400	$\frac{1}{6000}$
Ganges . . (Upper)	143,000	6,369,078,440	$\frac{1}{823}$
Hoang-ho .	700,000	17,520,000,000 ?	$\frac{1}{1464}$
Rhône . .	25,000	600,381,800	$\frac{1}{1528}$
Danube .	234,000	1,253,738,600	$\frac{1}{6846}$
Po	30,000	1,510,137,000	$\frac{1}{729}$

AN UNDERGROUND RIVER IN THE MAMMOTH CAVE, KENTUCKY

Naturally, when rivers are in flood their erosive power is greatly increased, so that a swollen river may carry ten or twenty times its normal amount of mineral matter. In the Nile in May, 1875, there were 4772 parts of solid matter in every 100,000 parts of water, and some rivers in flood are like thick pea soup The destruction wrought by turgid rivers may be very great and very rapid, especially when the water bursts suddenly through dams and embankments

We have already mentioned the devastation caused by the overflow of the Hoang-ho The Indus has sometimes worked almost equal havoc. In June, 1841, it burst through a temporary natural dam. "Houses and trees, men and women, horses and oxen, sheep and goats, were borne away at once, and all the alluvial flats in the bed of the river were destroyed in a moment, the flood passing Torbela, a distance of 550 miles, two days later, at the rate of 16 81 feet per second, or 11 4583 miles per hour . . Trees entirely disappeared from the Shayók Valley almost in an instant; and at Kulai, hundreds of miles lower down, about 500 of Rajah Golab Singh's army who were encamped in the bed of the Indus were swept to destruction. All the cultivated lands were swept away, and the once fertile Chach was sown with barren sands. . . Opposite Attock, the waters of the Kabul River were checked and forced backwards for upwards of 20 miles by the mighty waves of the inundation, and the fort of Akora and the village of Messabanda were overthrown, while the back-wave of the flood was felt up the comparatively narrow valley of the Indus for 10 miles above its junction with the Shayók. Lower down, the loss of property and life was not less than that described."


UNDERGROUND RIVER IN THE CHALK HILLS OF ENGLAND

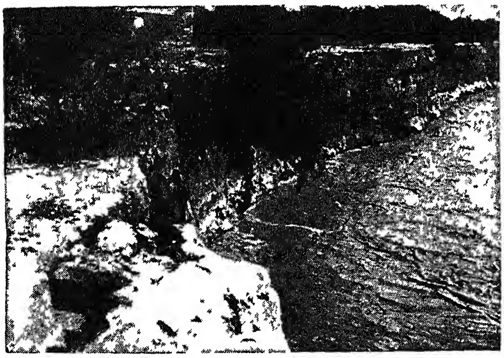
When a mighty river like the Amazon or the Mississippi is in flood, it devours its banks by the mile When the Amazon overflows, it becomes in parts a hundred or two hundred miles in width, and when it sinks and retreats to its original channel it undermines its sodden banks, so that they collapse into the water hundreds or thousands of yards at a time, carrying with them trees and animals Great masses of trees get tangled together, and tumble about in the currents "like marine monsters or drifting wrecks", while in some parts the river looks like broad meadows, from the accumulation on it of a green plant.

In the Mississippi, before man confined it between artificial embankments, floating rafts of trees were found on a colossal scale, and some of its tributaries were quite choked up with the flotsam and jetsam of forests. In many places a man might cross a great river on driftwood green with growing vegetation without knowing it. One great accumulation of trees on the Red River is known as the Great Raft, and for twenty-two years the federal government vainly labored to remove it. The Congo, Orinoco and Ganges bear similar woven rafts, of trees and driftwood, and covered often with luxuriant living vegetation. Sometimes the rafts break away from their moorings, and drift down the river like floating islands. They are sometimes seen fifty or a hundred miles out at sea off the mouth of the Ganges; and no doubt such rafts may float for long distances, and eventually carry animals and plants far from their native land.

Whether large or small, all rivers erode the land, and rapidly or gradually deepen their beds; and all over the world we find

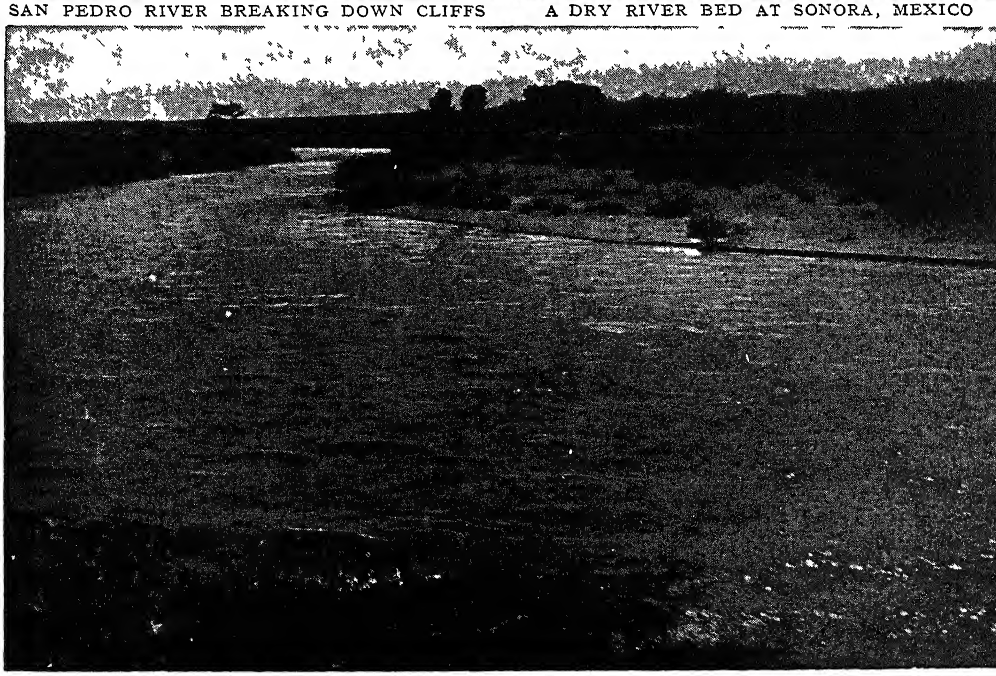
FROM RACING TORRENT TO STONY WASTE

THE COMPARATIVELY DRY COURSE OF THE SAN PEDRO RIVER IN SUMMER



SAN PEDRO RIVER BREAKING DOWN CLIFFS

A DRY RIVER BED AT SONORA, MEXICO



THE SAN PEDRO RIVER IN FULL FLOOD DURING THE RAINY SEASON

the excavations of rivers in the shape of glens and gorges, and ravines and barrancas and canyons. Some of the most remarkable river-cuttings in the world are the canyons of Arizona. Here the Colorado River and its tributaries, as if with a colossal knife, have cut gashes thousands of feet deep in a vast high plateau which extends between the western side of the Rocky Mountains and the head of the Gulf of California. The Grand Canyon of the Colorado is about 300 miles in length and 10 miles in breadth, with almost perpendicular sides 4000 or 5000 feet high, and along the center of the canyon is a gash, 1000 feet deep, in which the river flows. So numerous are these canyons, so steep their sides, that many rivers cannot be reached, and the only way to go comfortably across the country would be to use an air-plane. If a hunter should shoot an animal, and it should fall from the plateau down one of these canyons, it would require almost a day's journey for him to retrieve the body.

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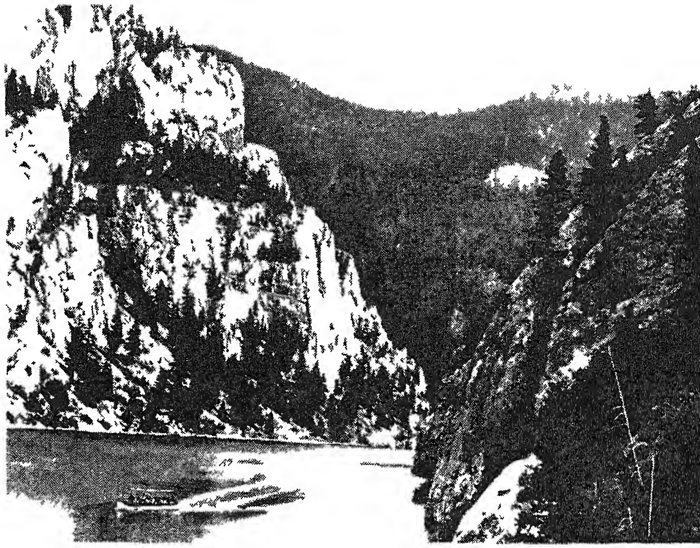
A MISSISSIPPI STEAMER WRECKED BY STRIKING A SUBMERGED LOG, NEAR NEW ORLEANS

In the Himalayas, mountain torrents have cut such ravines in the mountain walls that they serve as gateways to admit the warm air from the south, and thus moderate the climate on the north side of the range.

How quickly it is possible for rivers to excavate is seen in the case of the River Timeto, which in less than a hundred years made a cutting 50 to 60 feet wide, and 40 to 50 feet deep, through a dam of lava thrown across its channel during an eruption of Mount Etna; and it is estimated that in eleven years Niagara Falls wore away about 10,000,000 cubic feet of rock.

But rivers are not merely destructive, they are also constructive; they "draw down æonian hills", but they also "sow the dust of continents to be". Rivers do not retain forever in their water the soil and rock they erode; they carry it for a certain distance and then precipitate it. Indeed, destruction and construction, erosion and precipitation, proceed *pari passu*. Always when the speed of any sediment-laden river slackens, a certain amount of the sediment is deposited. Thus at the point where mountain torrents reach the plain there is often a fan-shaped deposit, with apex pointing up-hill, called a "cone" if somewhat thick and a "fan" if proportionally flat. In the case of large streams, such as occur in the upper basin of the Indus and in the Rocky Mountains, the fans may be many miles in diameter, and some hundreds of feet deep. For like reasons there is usually a deposit of sediment in the concavities of the curves of winding rivers. This is shown in the picture of one on page 196.

Again, when rivers overflow their banks, the current is checked, and a great part of the sediment they carry is necessarily deposited. It is a flood deposit of this kind that makes the rich alluvial mud of Egypt, on which the country's fertility and prosperity depend; and until the banking up of the Mississippi, continual overflows must have deposited an enormous amount of sediment on the surrounding country. For miles round Bâle are found pebble beds deposited by the overflowing Rhine, and the frequent floods of the Po have covered the plains of Lombardy and Piedmont with gravel.



The mountains make way for the river. Here the Missouri River cuts a passage through the Rockies near Helena, Montana.

Northern Pacific Railway

The magnificent gorge carved out by the Rummel River, near the city of Constantine in Algeria.

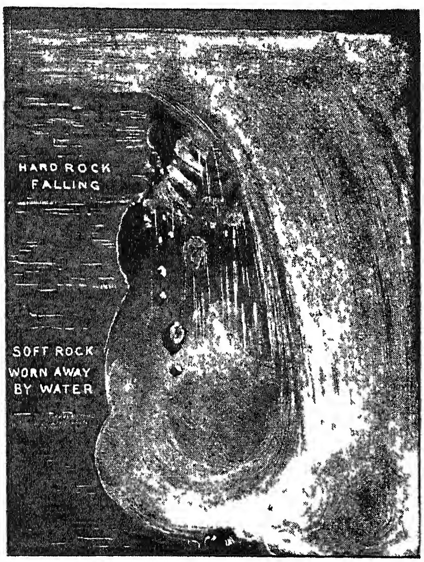
TWA

Santa Fe Railway

The Colorado River carves, hollows out and smooths the rock as it sculptures the mighty Grand Canyon

In many cases regular raised terraces are found running parallel with the river beds, these terraces being the product of precipitation during floods. As the terraces are raised higher and higher by layers of sediment, and as the river bed deepens, they become eventually above flood level, and are left high and dry.

Sedimentation also occurs when rivers flow into lakes, since the flow of the river is of course checked, and with consequent deposition of sediment. Where the river enters the lake the deposit spreads out in a fan over the bottom of the lake where the river enters. By degrees the sediment deepens, and eventually part, or even the whole, of a lake may be filled up. The Lake of Geneva, through which the Rhône flows, must once have extended fourteen miles up the Rhône Valley to St Maurice. In the time of the Romans, Port Valais was situated on the margin of the lake, but it is now two miles from the water's edge. When two streams flow into a lake, their sediment may be mutually deposited across the center of the lake, and eventually divide it into two. Thus the Lake of Thun and the Lake of Brienz, in Switzerland, are now separated by an arm of low-lying land about two miles wide, on which Interlaken is built, but it is probable that the lakes were originally one.



THE CAUSE OF THE RECESSION OF THE NIAGARA FALLS

Great as these alluvial deposits may seem, they do not equal in importance and extent the alluvia deposited in river estuaries. As rivers approach the sea, they flow more sluggishly, both because their bed is wider and because it is flatter, and thus at this time, and in this position, there is a special tendency to deposit sediment; and this tendency is increased by the fact that the salt water itself favors deposition. Sometimes the deposit takes the form of a bar or bank of gravel, sand or mud across the mouth of the river. At the mouth of the Mississippi there is a bar "equal in bulk to a solid mass one mile square and 490 miles thick", and it advances at the rate of about 300 feet each year.

Not bars and banks, however, but actual stretches of low land are the characteristic sedimentary deposits at the mouths of rivers. The low land thus formed is usually called the "delta" of a river, a name first applied by the Greeks to the alluvial tract at the mouth of the Nile because of its supposed resemblance in shape to the Greek letter of that name (Δ).

When we examine these alluvial tracts laid down by rivers, we are surprised at their extent. The so-called "Low Countries" are nothing more or less than the alluvial deposits of the Rhine, Meuse, Sambre, Scheldt and a few other streams.

The Rhône, even though it drops so much sediment in the Lake of Geneva, has still succeeded in making a delta in the Mediterranean, and adds to it every year about 140,000,000 cubic feet of sediment. Since the Roman period it has formed from 77 to 116 square miles. The Po works even more vigorously, advancing its delta at the rate of 230 feet a year, so that Ravenna, originally on a lagoon, is now 4 miles inland, and the port Adria no less than 14 miles from the Adriatic, to which it gave its name. At places the coast-line has encroached no less than 20 miles on the sea, and in time the upper end of the Adriatic will be filled up. On the other coast of Italy the Tuscan rivers are hard at work, and every year deposit 12,000,000 cubic yards of sediment within the marshes of the Maremma. The Tiber adds about 12 feet a year to the coast-line near Civita

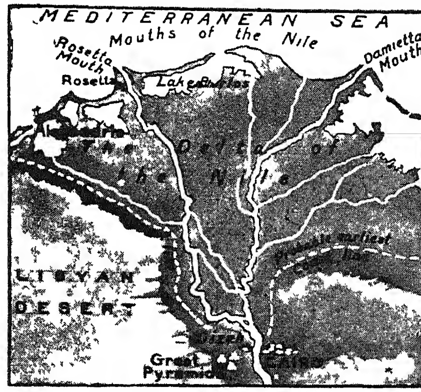
Vecchia; and the ancient harbor of Ostia, which was once at its mouth (hence the name Os, meaning a mouth), is now 3 miles inland, and half buried in mud. The Danube also is busy delta-making; and during the last 1900 years its delta has advanced 9 or 10 miles into the Black Sea.

But these deltas are small compared with those of the great rivers of the world. Take the delta of deltas, the alluvial deposit of the Nile. This is now 180 miles wide, and contains an area of over 9000 square miles. Memphis, which was once on the sea, is now 100 miles inland. All this land is a gift of the Nile; it has been made of its mud; and since almost all the mud comes down from the hills of Abyssinia, Egypt, geologically speaking, is an annex of Abyssinia. Yearly about 80,000,000 cubic yards of mud are debouched by the Nile. About two-fifths of this is added to the delta, while the rest is carried away by the sea, and eventually thrown down along the coast of the El Arish desert. The flooding of the river, of course, diverts much of the mud from the delta to Upper Egypt; and it has been calculated that the surface of the latter has been raised by sediment $6\frac{1}{2}$ feet in the last 1900 years.

Larger still is the delta of the Hoang-ho, whose yellow mud has made a tract of alluvium extending over nearly 100,000 square miles, and constituting one of the most important provinces in China. Once the mountainous mass of Shantung stood isolated in the sea; now it is joined to the mainland by alluvium. So great is the discharge of sediment that it has been calculated that in 66 days there is enough deposit to form an island 1 square mile in area and 118 feet in height; and new islands are, indeed, being constantly formed.

The combined delta of the Ganges and Brahmaputra covers between 50,000 and 60,000 square miles.

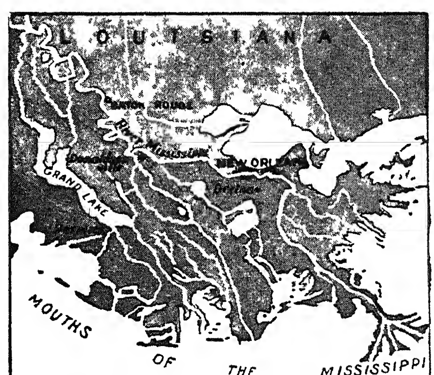
The Mississippi delta covers 12,300 square miles. It extends 220 miles into the Gulf of Mexico, and is advancing at the rate of 300 feet yearly. This, however, by no means represents the total deposit of the great river, which is not only building this delta above the waves, but is laying in the bottom the foundations of a far bigger one. The total annual discharge of solids by the Mississippi, not including solids in solution, has been calculated at 7,500,000,000 cubic feet — enough to bury the whole of Manhattan Island to a depth of over 10 feet. The delta of the Indus extends over an area of 3000 square miles.



THE DELTA OF THE NILE

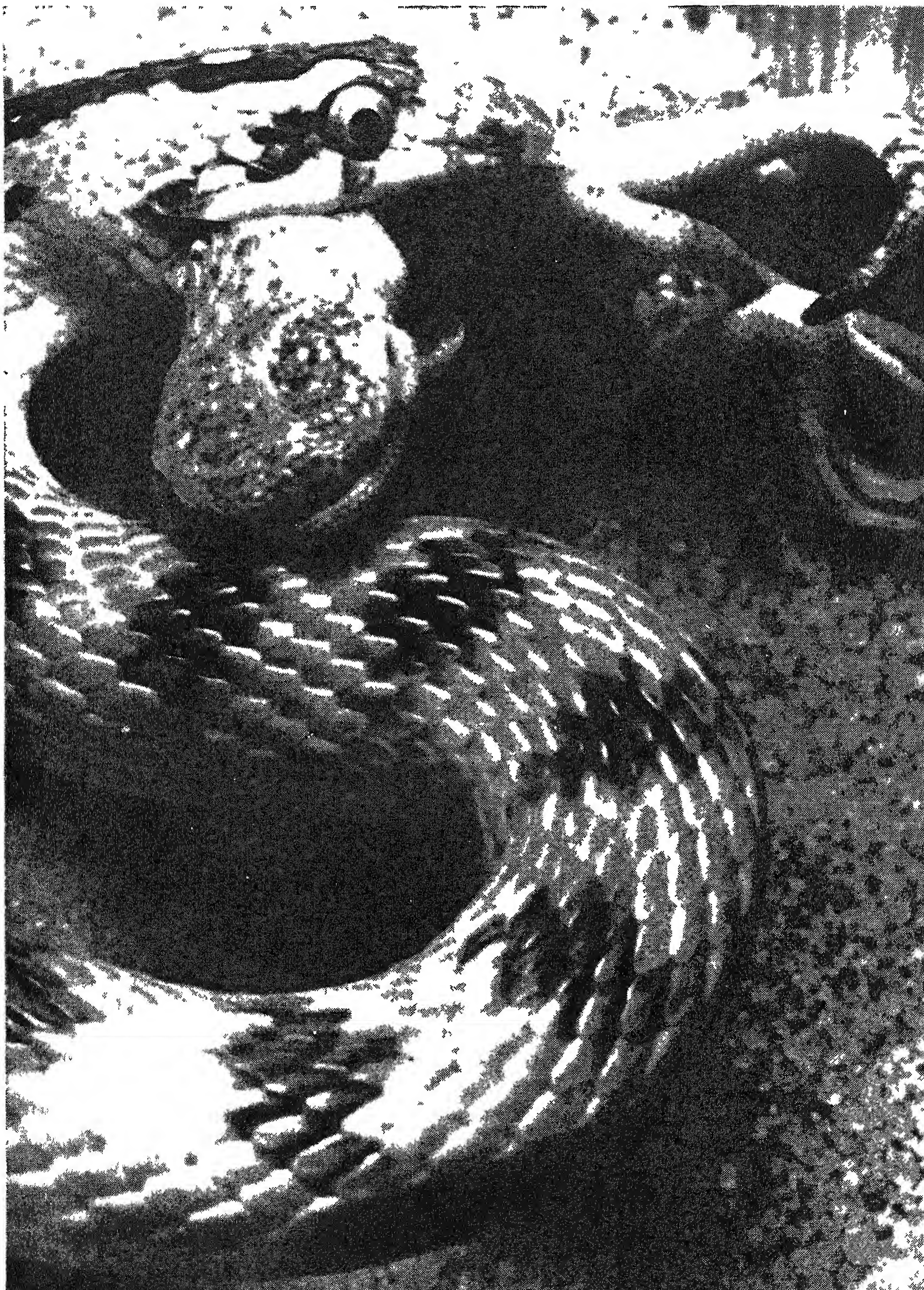
That of the Amazon is nearly 200 miles broad; and it would be much broader were it not that a great deal of its mud is swept hundreds of miles out to sea

When we consider all this constructive work done by rivers, we realize that they build up almost as quickly as they pull down; and when, later on, we come to



THE DELTA OF THE MISSISSIPPI

deal with the origin of mountains, we shall see that the new mountains are largely due to the mud of the old ones, and that the action of the waters disintegrates the oldest and hardest layers of the earth's crust and scatters them over the globe, to be reformed into rocks usable in man's industries.



Standard Oil Company (N. J.)

The sharp-nosed snake (*Lytorhyncus ridgewayi*) devouring a fringe-footed sand lizard. This striking snake is an inhabitant of Arabia, an inveterate burrower, it is generally found in sandy areas.

THE BALANCE OF NATURE

Illustrations of the Struggles for Existence Continually Going on between Different Types of Life

BIOLOGICAL CONCEPTION OF DISEASE

IN preceding chapters of this section we discussed the doctrine of organic evolution, not least with reference to the work of Darwin; and, having found that a new science of heredity is required before we can attempt to answer the question *how* organic evolution has come about, we then discussed in other chapters, our existing knowledge of what is now called genetics. Not yet, as we have seen, can positive science explain the origin of those "originating variations", as Professor Bateson calls them, upon which the origin of species depends; and that is the humbler verdict of our own time upon the problem which many asserted Darwin to have solved once and for all in 1859.

But this is very far from meaning that the life-work of that master-seeker was fruitless or unavailing. On the contrary, having done our best to deal with the more universal and philosophical aspects of the problem of evolution, and having seen that we must confess our ignorance while we search for more minute and exact facts of genetics, we must now return to another aspect of the science of life. Almost ignoring the problems of origin and destiny, we must again survey the world of life as we find it at any given time, such as our own, and we must look afresh at certain great facts, of the utmost practical importance, for which the long preceding discussion of theory was no bad preparation, and in which we have no better guide than Charles Darwin. Never again will men attribute to natural selection the powers of Creative Deity, as Darwinism, logically interpreted, seeks to do; never again will they have to try to solve the problems of evolution without the help of modern genetics.

But we are surely very far from the day when we can do without Darwin's profound and searching observation of the facts of the living world as they are displayed at any given time. We reject his theories and the colossal superstructure of mechanical philosophy built upon them by his followers, but we shall do well to learn humbly from him, as a guide to the world of life as it exists at any moment.

It has advisedly been asserted that this is a matter of practical importance, and we shall in due course discover the full significance of that objective, when we realize that the facts of death and disease, and the problems of maintaining the health and prosperity of mankind, can mostly be resolved into Darwinian terms of the struggle for life, the balance of nature, and the mutual adjustment and competition of the myriad species of the living world.

Another way of stating this idea is that the modern conception of the greater part of what we call disease, the conception whose practical establishment we owe to Pasteur, is *biological;* it is the conception of disease as a natural fact of the living world, which has a biological explanation and must be biologically understood if it is to be placed within human control.

Darwin, of course, wrote before the modern era in the study of disease, and knew nothing of what Pasteur and his followers were to show; but it remains true that, though Darwinism can no longer be regarded as the key to the supreme problem of organic evolution, yet the Darwinian view of the living world is that alone which gives us the explanation and understanding of the problem of disease as elucidated by Pasteur and his successors.

For the theory of disease we must return to Darwinian principles

In a word, they have clearly shown us that consumption, for instance, is due to a living plant, and thus this most deadly of all diseases is none other than an illustration of the Darwinian theory of the struggle for life between one species and another. To Darwin we must therefore return, for a fresh beginning, if we are finally to place ourselves abreast of modern knowledge in these matters which so closely and personally concern us all. And it is not unbecoming to note that, though the present generation rejects Darwin's conclusions on the main issue, on the other hand it goes back to Darwin for the foundations of the true theory of disease, as that theory is being slowly built up by contemporary students.

This is the inevitable and just result of honest labor in science. Over and over again, as in this case, the theory or theories fail to withstand the test of time; but if the facts on which they were built are themselves well and truly laid, then the laborer has not toiled in vain. In the upshot we shall clearly see that our present attitude towards the problems of disease, and our present methods of solving these problems, methods which are meeting with ever-accelerated success, are based upon those biological ideas, those ideas of living nature as a whole, which Darwin first gave to the world.

And our first business therefore now is to remind ourselves of what he saw and said; for there is a great deal more in the "Origin of Species" than that theory of natural selection which we have already discussed.

The enormous increase in numbers of every species upon removal of checks

In the seventh chapter of this section we saw how rapidly living creatures reproduce themselves and multiply under favorable conditions; and this tendency is so important that Darwin concluded his own study of it with the following words, to which we must attach the weight he recognized in them.

"In looking at nature, it is most necessary to keep the foregoing considerations always in mind — never to forget that every single organic being may be said to be striving to the utmost to increase in numbers; that each lives by a struggle at some period of its life; that heavy destruction inevitably falls either on the young or old, during each generation or at recurrent intervals. Lighten any check, mitigate the destruction ever so little, and the number of the species will almost instantaneously increase to any amount."

In due course we shall see how these words apply to species of which Darwin had never heard or dreamed, such as *Bacillus tuberculosis*, as well as to *Homo sapiens*, and to the mortal struggle between them, which man, now roused at last, intends shortly to win. But all such cases as that involve a particular form of the "struggle for life", and the "balance of nature", which we call parasitism; and before we deal in detail with parasitism and the most important parasites we must try to get a just and adequate idea of the balance of nature as a whole.

First, we must observe that our study now concerns itself with just that aspect of the struggle which we put aside as relatively unimportant when we were discussing "natural selection". Natural selection and the struggle for life may operate both between different species — as, lion *versus* tiger in India, or man *versus* tubercle bacillus anywhere — and between different members of the same species.

The problem of disease as a struggle between different species

Darwin himself carefully insists that the most important part of the struggle from the point of view of natural selection and evolution is that between different members of the same species. This has been recently insisted upon afresh by the most distinguished of recent Darwinians, Sir E. Ray Lankester, and we were the more careful to regard it in an earlier chapter, because this is the aspect of "natural selection" which is commonly ignored in popular discussion of the subject.

But now the time has come when, for reasons concerned with the problems of disease, we must carefully recognize the importance of the struggle between one species and another. That struggle may be even less important, from the point of view of the origin of species, than Darwin himself thought it; but we are to learn that it is not only of enormous importance in relation to the problem of the origin of disease, but practically *is* that problem.

The delicate and unstable balance between species all the world over

If we consider the living world at any moment, we see a vast number of species, animal and vegetable, high and low, some very numerous, some very scarce, some spread everywhere, others confined to very limited parts of the earth's surface; and if we go on watching, we observe that, on the whole, these proportions, numbers and particular distributions of species remain constant.

On the whole, there is a balance between them, which we are wont to call the balance of nature. We recognize at once that it is an extremely delicate and unstable balance, sensitively fluctuating from moment to moment, but yet there is a balance on the whole. Given some constancy of external conditions, no violent alteration of climate, no interference by man, we find that, though all species are striving to multiply, on the average none either increase or decrease in numbers.

There is a balance between them perhaps even more closely analogous than may at first appear to what was once known as the balance of power in Europe. Each species has a "sphere of influence", a country which it occupies — as if we said Thrush-land, or Oat-land, instead of Angle-land or Scot-land — a "hinterland" which it controls, even remote spots which it occasionally or regularly colonizes, as in the case of migrating birds. This is a state of balance like that of Europe at the beginning of this century but it is also a state of struggle, none the less real because largely carried on in secret, also like that of Europe. Just as the different varieties of men in Europe, grouped as nations, are perpetually struggling against each other for food — which is what the struggle for life or power ultimately comes to — so the different species of the living world are perpetually struggling against one another; and the first fact which we have to learn is that the balance of nature, which might be thought peaceful — as the condition of Europe was thought to be — is really active, passionate, military *à outrance*.

The difficulty of realizing how universal and fierce is the struggle for life

We find it very difficult to realize the facts, because we are misled by what we see, and do not realize what is going on underneath, just as we do not realize how the chancelleries and the industries of Europe are all the time fighting each other. But if we fail to appreciate the real meaning of the balance of nature, and fancy that it is the result of agreement, or arbitration, or mutual toleration, or lack of desire for more, on the part of living species — at least we have the excuse that Darwin himself found it difficult to keep in the forefront of his own thought the fact which he so clearly demonstrated Here are his own weighty and memorable sentences which should help to impress it on our minds.

"Nothing is easier than to admit in words the truth of the universal struggle for life, or more difficult — at least, I have found it so — than constantly to bear this conclusion in mind. Yet unless it be thoroughly ingrained in the mind, the whole economy of nature, with every fact on distribution, rarity, abundance, extinction and variation, will be dimly seen or quite misunderstood. We behold the face of nature bright with gladness, we often see superabundance of food; we do not see, or we forget, that the birds which are idly singing round us mostly live on insects or seeds, and are thus constantly destroying life; or we forget how largely these songsters, or their eggs, or their nestlings are destroyed by birds and beasts of prey; we do not always bear in mind that, though food may be now super-abundant, it is not so at all seasons of each recurring year."

Nature a sensitive expression of infinite and warring activities

So wrote Darwin, but we now have this notable advantage over him — that we are able to bring in the modern idea of disease to our aid, and to confirm his views of the real meaning of the "balance of nature" as the resultant of unceasing struggle, by our appreciation of the unceasing struggle between man and microbe which goes on under the superficially peaceful surface of our lives.

If we follow Darwin's own observations we begin to see what this balance of nature really depends upon, and how intensely unstable it is — just because of the infinite and warring activities of which it is the sensitive expression. Thus writes Darwin: "On a piece of ground three feet long and two feet wide, dug and cleared, and where there could be no choking from other plants, I marked all the seedlings of our native weeds as they came up, and out of 357 no less than 295 were destroyed, chiefly by slugs and insects. If turf which has long been mown — and the case would be the same with turf closely browsed by quadrupeds — be let to grow, the more vigorous plants gradually kill the less vigorous, though fully grown plants; thus out of twenty species growing on a little plot of mown turf (three feet by four) nine species perished from the other species being allowed to grow up freely."

The enlarged view of the struggle for life seen by the microscope

In these famous observations Darwin saw, and we see, how real is the struggle between species, and we can indefinitely supplement what he could see, by means of the modern microscope, which has shown us the soil crammed with tiny forms of life, animal and vegetable, kinds of amœbæ and molds and bacteria, which are all struggling with each other and with the visible plants; and we begin to learn how the visible result, such as the survival of a certain eleven species and the death and extinction of a certain nine, out of twenty, very largely depends upon the invisible struggle for life under the surface of the ground, and the balance of species which results there. For we are finding that the success of such and such a species as against another, as of wheat rather than weeds, may be essentially due to the particular "balance of nature" between the microscopic vegetables that cram the soil — if certain of those preponderate, the weeds will flourish; if others, the wheat will flourish.

Put in another way, this may simply mean that wheat is subject to epidemics and parasites, as man is, and that the survival of wheat, or the death-rate among young seedlings of wheat, may be due to the balance of nature in the soil which is their food, just as the infant mortality in any given year may be modified by the "balance of nature" between the various species of microbes that flourish in the food given to babies.

This, the reader will see, is simply a revelation. We realize that the "balance of nature" and the "struggle for existence" are illustrated *everywhere* throughout the living world.

The conquest of disease—mastering life that would live on man

Wheat has its so-called "diseases", just as man has, and struggles against microbes which destroy or poison its food (the soil); is helped on by other microbes, which destroy the dangerous microbes, just as man fights against the microbes which infest *his* food, or is fortuitously helped by other microbes (such as the microbe of sour milk), which keep down the numbers of the dangerous microbes. The death-rate among wheat seedlings or human seedlings, and the consequent balance of nature between wheat or man and their respective visible competitors, may thus depend upon the result of the struggle for existence between the particular microscopic forms of life found in the soil in the one case and in milk in the other case. Having grasped this, let us add the further complication that man is growing the wheat to live upon, that man provides opportunity for the wheat and favors its growth and multiplication only in order that, a little later, he may destroy and con-

sume it, which means that man both struggles for and struggles against the species we call wheat; and further, that the result of this particular balance largely determines the multiplication of man and his power of struggling against his special competitors, such as the tubercle bacillus — and we begin to realize what the struggle for existence and the balance of nature mean, to a degree which was never imagined even by the mind of Darwin himself.

And the student will already begin also to see what we mean when we speak of the *biological* conception of disease; and to see that only in biological terms like those which Darwin taught us to understand and employ can man hope to achieve the "conquest of disease" — which seems now to mean the master hand over those other forms of life which try to live upon the food *he* requires, or, more daring still, try to live in his own blood and upon his own tissues.

Darwin's foreshadowing of the parasitic view of disease

But if we proceed with our survey of Darwin's pioneer work in this field we shall see that his splendid thought and observation led him to the very gates of the knowledge which we now possess, for he did not omit the fact of parasitism, nor fail to see that this is an aspect of the struggle between one species and another. Here is the truly remarkable paragraph which seems to have escaped previous commentators, but which serves as an exact introduction to the modern view of disease.

"When a species, owing to highly favorable circumstances, increases inordinately in numbers in a small tract, epidemics — at least, this seems generally to occur with our game animals — ensue; and here we have a limiting check independent of the struggle for life. *But even some of these so-called epidemics appear to be due to parasitic worms, which have from some cause, possibly in part through facility of diffusion amongst the crowded animals, been disproportionately favored; and here comes in a sort of struggle between the parasite and its prey.*"

Darwin vindicated by Pasteur's discovery of parasitic microbes

We have italicized the last sentence in order to indicate its interest and importance as foreshadowing views of disease which are now becoming familiar to all of us. Instead of game animals, living too crowded together, let us consider the case of human beings in conditions of overcrowding, and, instead of a parasitic worm, let us think of a parasitic microbe like that of consumption. At once we see that Darwin wrote words which Pasteur and his followers were soon to justify when he said, "Here comes in a sort of struggle between the parasite and its prey." It is that "sort of struggle", which Darwin thus almost apologetically included under his general theory, that now is seen, by means of the "germ-theory" of disease, to be probably the most important of all the aspects in which Darwin's ideas illuminate and guide us.

But we must be careful to observe that the "balance of nature" has a double aspect. It does not merely depend upon cases where one species fights against another, but also includes innumerable cases where species serve one another. As we have already seen, and as Darwin expressly noted himself, we have no instance in nature of one species being adapted *in order to* serve another. Each species for itself is the rule.

The balance of nature dependent upon mutual service as well as competition

But the balance of nature is, nevertheless, largely dependent upon the fact that species incidentally and accidentally serve one another — as in the case, familiar to everybody, of the birds which eat stone-fruit, thus serving themselves, but thereafter effect a scattering of the stones, so that the seed is spread and sown, and the bird, in serving itself, thus happens to serve the species which it attacks. The balance of nature comprises innumerable examples of this kind of relation, and indeed largely depends upon them.

We must therefore beware of supposing that though species live only for themselves

their interests are therefore inimical to those of all other species. Except for the cases of the essentially debased and vicious thing called parasitism, that is far from true. The balance of nature largely means that the various species, in serving themselves and living their own lives, serve each other. Man fights against and masters other species; but if all other forms of life were suddenly to disappear, man would follow them after a brief interval of cannibalism.

To the supreme example of this balance of living species we have already made some allusion, and we need scarcely do more than remind ourselves of it here, for it depends upon those facts of the green leaf which the next chapter will discuss. It is, of course, the relation between the vegetable and the animal kingdoms.

The true relation between different species generally reciprocal

Perhaps it is a rather one-sided sort of balance, for indeed the vegetable kingdom could survive if animals were to vanish, while animals are absolutely and wholly dependent upon plants, in virtue of the powers of the chlorophyll of green leaves. Nevertheless, as our illustration of the bird and the fruit-tree serves to show, and as is further shown by the immensely important function of insects in the pollenization of flowers, there is no doubt that the vegetable world as a whole is greatly the gainer by the coexistence of animals, even though animals as a whole are, in a sense, "parasitic" upon the green plant. Thus the two great divergent lines or stems of the "tree of life", which have been developing along their own lines for so many years, are naturally interdependent, and their evolution and development could not have achieved present results if, at every age and in a myriad ways, plants and animals had not been reacting upon each other.

It is fair, however, to the animal world, including ourselves, also to add that, though we are undoubtedly dependent for our "daily bread" upon the vegetable world, this relation can scarcely be called parasitism if, in point of fact, it works out for the advantage of the vegetable world, as it does. The bodies of animals, when they die, are reduced to simpler chemical compounds, and finally serve as food for plants — even the plants of the very kind upon which the living animal fed. Thus the relation is reciprocal; and what we call the balance of nature may also be described as "the cycle of life", in virtue of the cyclic, circular or wheel-like way in which the forms of life serve, or take advantage of, each other.

The lichen as an illustration of symbiosis, or partnership

No better illustration can be found of what is not parasitism, though not unlike it in non-essentials, than the lichen, which is really an alga, or green plant, and a fungus living together. Each species, no doubt, is for itself, but each serves as well as gives, and therefore there is no degeneration. The alga possesses chlorophyll, and can therefore feed itself from the air, while the fungus, which avails itself of the food thus obtained, provides shelter, mechanical support upon the rock or stone, and also water essential for both alga and fungus. This is technically called *symbiosis*, or living together. Symbiosis is not parasitism, but obviously there is a temptation, so to speak, for either partner to become "slack", to leave too much to the other, and become parasitic, if the other permits. The whole living world is a symbiosis, as we have already tried to show, and not least of all the magnificent partnership between the animal and the vegetable kingdoms. But if we remember that each species is all the time essentially concerned with itself and its own interests, we shall see how symbiosis always runs the risk of leading the way to parasitism, with its consequences of failure, disease and death.

Such considerations will help to prepare us for the study of parasitism, the evolution of parasitism, and thus the genesis, and possible human control, of what we call "disease". Meanwhile let us observe that while symbiosis is a vital principle in the world of life, parasitism is a mortal one, and the transition is tragically easy.

These are truths of profound origin, and therefore of wide application. They apply not only to the "partnership" of alga and fungus upon a rock, but to every partnership between man and man, or man and woman. If marriage is a symbiosis, it is a vital triumph; if it is a parasitism, it will be a mortal failure.

The changes made in a countryside by the planting of the Scotch fir

But there are countless relations between species, determining their lives, other than that which we call symbiosis. Darwin noted many striking instances in his early work. Thus, he observed how, in Staffordshire, the introduction of a single tree, the Scotch fir, had changed the number and character of the living species upon the heath where they were planted, as compared with the unplanted part of the heath. The change in the vegetation, on passing from the one to the other, was "more than is generally seen in passing from one quite different soil to another".

The proportions of the heath plants in the planted part were quite different; many species of plants were found in the plantations and not upon the heath; six insect-eating birds were found in the plantations, and not upon the heath, which had two or three distinct insectivorous birds. Near Farnham, in Surrey, Darwin again studied the associations of the Scotch fir, and there he found that cattle absolutely determine its existence. All over hundreds of acres of uninclosed heath, he found tiny seedlings of the fir, which had been perpetually browsed down by cattle. One little tree, "with twenty-six rings of growth, had, during many years, tried to raise its head above the stems of the heath, and had failed. No wonder that, as soon as the land was inclosed, it became thickly clothed with vigorous young firs."

How insects may control the existence of cattle

Then we learn that, while cattle can control the Scotch fir, in many parts of the world insects determine the existence of cattle. Thus, in Paraguay there is a certain fly, an enemy of cattle, horses and dogs, which are thus kept down, though north and south of Paraguay they run wild. These flies are themselves checked in numbers by other parasitic insects. Hence, if certain insectivorous birds were to decrease in Paraguay, the parasitic insects would probably increase, which would lessen the number of flies, thus increasing the number of cattle and horses, with the result that the vegetation would be markedly altered. But this alteration would profoundly affect the insects which live upon the vegetation, and thus the birds which live upon those insects. Thus, we are back to the birds with which we began, and this case suggests the complexity of the balance of nature in high degree. We might think it a rare and peculiar one, but Darwin closes his discussion of it with these weighty words, never more pertinent than today:

"Not that under nature the relations will ever be as simple as this. Battle within battle must be continually recurring with varying success; and yet in the long run the forces are so nicely balanced that the face of nature remains for long periods of time uniform, though assuredly the merest trifle would give the victory to one organic being over another. Nevertheless, so profound is our ignorance, and so high our presumption, that we marvel when we hear of the extinction of an organic being; and as we do not see the cause, we invoke cataclysms to desolate the world, or invent laws on the duration of the forms of life."

Darwin's interpretation of the balance of nature justified by all modern discovery

Everything that Darwin saw and foreshadowed in this direction has been confirmed since his day. His acute observation and interpretation of the balance of nature and the astonishing relations between species "in ever-increasing circles of complexity" are justified by every modern discovery in the realm of tropical disease and of disease at home. He has prepared the way for our minds to appreciate the fact that man is simply one of the species concerned in these immeasurably various and complex cycles, and

that what we call disease in him is simply, in most cases, an aspect of the balance of nature and the struggle for existence, as Darwin first clearly perceived and defined them more than fifty years ago.

Further, we begin to realize the full weight of his words when he says that the balance is usually so delicate that the merest trifle would give the victory to one organic being over another. Man is himself the persistent and incessant disturber of the balance of nature.

The balance of nature disturbed mostly by men

He keeps on introducing a novel species — namely, himself — into all parts of the world. He introduces vegetation and destroys it. He cuts down forests, diverts streams, makes canals, builds cities and slums, takes the rabbit to Australia, exterminates his fellows here and there, in places where they have, by long evolution, become well balanced with the rest of the living species there residing, and substitutes forms of human being evolved under other skies and with different powers of resistance. The consequences are colossal. All manner of "new" "diseases" appear, because the balance of nature has been disturbed, and this or that species, long kept under, finds itself in a very paradise of food and opportunity — like the tubercle bacillus in the "Paradise Alley" of many a slum.

All these facts and problems must henceforth be looked at biologically, through eyes which Darwin has taught to see, and in terms of the warring, hindering, helping, elbowing lives of species, high and low, man, mouse, mold, microbe — all striving for life at all costs, and playing into each other's hands, or utterly annihilating each other, as the conditions of the struggle may determine. To understand those conditions, and thereafter to control them in the interests of his own species above all others, is the urgent task of man.

One more illustration must here be quoted, for Darwin has made it classical, and many are familiar with it who know nothing of the great principle which it illustrates, and which we now see to mean vastly more for the life of man than ever Darwin could guess. The humble-bee was proved by Darwin to be necessary for the fertilization of the heartsease and certain kinds of clover, which other bees do not visit, as they cannot reach the nectar. And here is Darwin's famous conclusion:

"Hence we may infer as highly probable that, if the whole genus of humble-bees became extinct or very rare in England, the heartsease and red clover would become very rare, or wholly disappear. The number of humble-bees in any district depends in a great measure upon the number of field-mice, which destroy their combs and nests; and Colonel Edward Newman, who has long attended to the habits of humble-bees, believes that 'more than two-thirds of them are thus destroyed all over England.' Now, the number of mice is largely dependent, as everyone knows, on the number of cats; and Colonel Newman says, 'Near villages and small towns I have found the nests of humble-bees more numerous than elsewhere, which I attribute to the number of cats that destroy the mice.' Hence it is quite credible that the presence of a feline animal in large numbers in a district might determine, through the intervention, first of mice and then of bees, the frequency of certain flowers in that district."

Parasitic warfare between beings wide apart in the scale of nature

One final sentence from our great teacher must be exactly quoted, and then we may pass on to the conditions of the problem as it faces us today. He concludes his wonderful study of this subject with the words: "The dependency of one organic being on another, as of a parasite on its prey, lies generally between beings remote in the scale of nature."

What a significant and profound anticipation, as if seen with the prophetic eye, of what was about to come — the work of Pasteur and his pupils, the discovery of the microbic nature of disease, the work of Manson and Ross on malaria, its parasite and its mosquito, and all that is even now being added to these great achievements!

PLANTS AND THEIR PARTNERS

Attractions Offered by Flowers to Birds and Insects, and the Value of Their Visits

MUTUAL SERVICES BY PLANT AND ANIMAL

VERY much is said in scientific writings of the struggle for existence, and emphasis is placed on the selfishness of plants and animals as shown in the way which the stronger crush or starve out the weaker. But through this very struggle for existence there have been developed many beautiful and helpful relationships among plants and animals, one of the most interesting being the partnership established between flowers and insects for reciprocal help. To understand how this partnership has come about we need first to consider the problems confronting plant life.

In order to succeed, a plant must first find a place in which to develop from the seed and it must have water, air, light and soil or its equivalent by means of which it can make its food and keep on living long enough to develop its seeds and scatter them where they may find an opportunity to grow. It is in the matter of developing seed, a most important phase of plant life, that this partnership between plants and insects has come into existence. It used to be supposed by the older botanists that all that was necessary to insure perfectly satisfactory fertilization in plants was that the pollen from one flower should be placed upon the stigma of another of the same plant. It was not, however, until Charles Darwin, in 1857 and 1858, in his work on "Cross and Self-Fertilization in the Vegetable Kingdom", drew attention to the fact that some plants were entirely dependent for their fertilization on pollen being transferred from one to another, that the value of cross-fertilization became recognized.

From his own labors, and those of his fellow-botanists, it was soon ascertained that almost all the flowers which exhibit brilliant colors and delicious odors, or are otherwise attractive and conspicuous, flourish far better when, instead of being fertilized by their own pollen, they secure pollen from other flowers of their own species. This fact was then established by actual experiment, simply by treating a flower with its own pollen and treating another flower of the same kind with pollen from another individual. The result was that the number and vitality of the seeds which resulted was much greater in the case of the cross-pollination than it was in the case of the self-pollination.

This experiment by Darwin shows that the plants which can secure cross-pollination will develop more and stronger seeds, and will, therefore, as the centuries pass, out-distance those which produce fewer and weaker seeds. But plants are stationary; they cannot wander about and get pollen from other plants to perfect their own seeds, so they must utilize other means. Probably the earliest way of meeting the problem was by developing such quantities of pollen that the wind, however vagrant and capricious in its movements, would take up the pollen and carry it and sift it over flowers of other plants of the same species. Many plants still depend upon the wind as a partner; the pines and the corn are instances of these; however, this is very wasteful of pollen, which is an expensive product. Formerly when the pines in the forests around the Great Lakes were discharging their pollen the water would be

yellow with it for miles from the shore, — all wasted because the wind happened to be blowing in the wrong direction. Surely it is not economical for a plant to depend upon the wind for bringing and carrying its pollen! But here were insects which visited flowers to gather pollen for their own food every day; if they could be induced to carry the pollen, what a saving it would be!

To understand how this is accomplished and how the plants fulfil their side of the partnership we must give them a little detailed study.

The "essential" parts of a flower

First of all there are the parts of a flower which the botanists call "essential" because they must be present in order to produce the seed, which is the real reason for the existence of any flower. These parts are the pistil, in which the seeds are matured, and the stamens, in which is developed the pollen which must be used to make the seeds grow.

The pistil may consist of a seed box or ovary, in which the seeds grow, and the stigma, which is a spongy and sticky surface which catches the pollen and through which it sends down tubes to reach the

Pollen grains greatly enlarged.

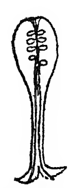
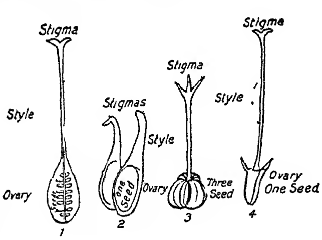


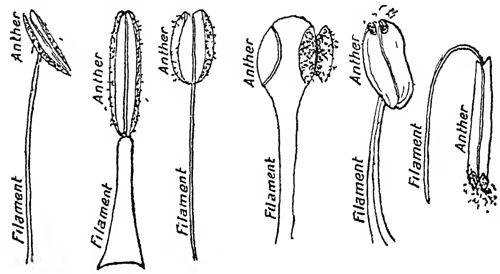
Diagram of a pistil showing two pollen grains on the stigma and the pollen tubes reaching down to the young seeds



Some different forms of pistils.

ovules and enable them to grow into seeds; often there is a stem called the "style" between the ovary and stigma for the purpose of holding the stigma up or out where it may receive the pollen from the pollen carrier to a better advantage. The length and shape of this stem is determined by this necessity.

The stamen may consist of two parts: the anther or pocket in which the pollen is developed is essential, and sometimes this is all there is to the stamen; but sometimes there is a stem to the anther called the "filament", which holds the anther up or out where the pollen may be shed in the path of the visiting insect, or where the wind can get at it to carry it away. The anthers or pollen pockets in each species of plants open in a particular way in order to let the pollen out in the best possible situation for being carried; some open like books, some like boxes and some like bags, mouth downwards, and some like pockets.



Some different forms of stamens, showing the different ways they discharge their pollen.

The petals, which are usually colored so as to attract the living pollen carriers, are often changed greatly in form in order to force the insects to bring and carry pollen effectively.

The sepals, whose particular business is to protect the flower while it is in the bud, are likewise modified and they often remain to protect the seeds as well.

The rewards offered the insects

The flowers are generous in their rewards for carrying their pollen; they furnish enough pollen so that the bees and beetles and flies may have all that they wish to eat, and the bees may have plenty to carry home and feed to their young. In addition to the pollen, the flowers in many instances give sweet nectar for their pollen carriers to drink and which the bees carry home and make into honey. Nectar is the chief food of butterflies and many species of moths.

Advertisements to attract visitors

The advertisement in most common use by the flowers which attracts our attention is color. The petals of the flower from the plant standpoint are flags of blue, red, yellow, purple or white which

they "wig-wag" in their own way to attract to them the insects and the humming-birds. The second advertisement is odor, which is probably even more important than color to plants in calling the attention of insects to their wares; for insects have powers of smell far beyond ours. Although no insects are possessed of a nose that in the least resembles ours, yet they have wonderful organs in their antennæ for detecting odor at a very great distance. When the odors of flowers please us we call them "fragrant"; but the odors of some plants we find extremely disagreeable; however, they are just the kind of smells that attract certain kinds of insects which the flower needs to carry its pollen.

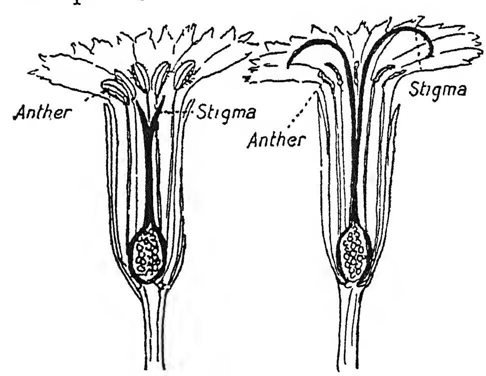
An example of the perfectly exquisite way in which insects and some flowers are adapted to help each other is that seen in cases where the scent of the flower becomes obvious exactly at the time when the flight of certain insects begins. Some of the honeysuckles and petunias, which have a very faint smell, or none at all, during the day, are powerfully scented in the hours of the evening, at which time the particular insects which visit them are on the wing. The same thing is true of some of the pelargoniums, the visitors in this case being moths. As one might expect, many flowers which are acutely scented during the daytime, when the butterflies are visiting as well as the bees, become perfectly void of smell after sunset, when these insects disappear. One cannot, in short, doubt that the second great attraction a flower can offer in order to help its own cross-pollination is the possession of a scent or odor obvious, at least, to some insects, even if unperceived by man, and emitted during certain times of the day or season when particular insects can exhibit activity.

The hospitable "door step" and guide lines

The most important convenience offered by flowers to their pollen carriers is for the short-legged insects like bees, and consists of an alighting place. Usually one or more petals are changed in form to make a "door step" on which the insect may rest while probing for nectar. The sweet pea, pansy and mint are instances illustrating this. Another convenience is guide-lines of different colors which converge and point like so many fingers to the opening that leads to the nectar well. Often the margins around the opening to the nectar well are of contrasting color and show where the sweetness lies. Still another is found in the form of the nectary which is adapted in length and size to the tongue of the insect which carries the pollen. This is well shown in the long, deep nectar tube of the *Nicotiana*, just fitted for the delectation of the long-tongued sphinx-moth, which is its partner. Some flowers save the time of the bees by changing color as soon as they are pollinated, like asters and the lupines; the flowers in the white clover not only change color but bend downward as soon as pollinated, — a very convenient practice to save the time of the too busy bees.

Devices to prevent self-pollination

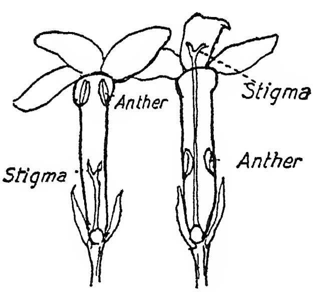
The most common of the devices to prevent self-pollination are as follows: (1) The stigmas ripen before the pollen of the flower is ready to be shed; or the pollen is shed and gone before the stigmas ripen as is the case with the common



Early stage of garden pink in which the pollen is ripe but the stigma is not. Later stage in which the pollen is gone and the stigmas are ripe.

garden pink and the hollyhock. (2) The flowers that produce the pollen grow on one plant and those which produce the seeds grow upon another as is the case with the pumpkins, cucumbers and willows; or they grow on different parts of the same plant as in the maples.

(3) Two forms of flowers are developed with stigmas of one kind placed in a special position to receive the pollen discharged from the other type of flower as is the case of primroses and bluets (*Houstonia*). If we look carefully at the bluets we find two forms of flowers: (*a*) Those with a two-lobed stigma protruding from the opening of the flower tube. (*b*) Those where the throat of the tube seems closed by four anthers which join like four finger-tips pressed together. In opening the flower, we observe that those which have the stigmas protruding from the tube have four anthers fastened to the sides of the tube about half way down; while those that have the four anthers near the opening of the tube have a pistil with a short style which brings the stigmas about



Bluets which, like the primroses, have two forms of flowers with stigmas and anthers arranged so as to secure an exchange of pollen from insect visitors

half way up the tube Thus an insect visiting a flower (*a*) gets her tongue dusted with pollen from the anthers at the middle of the tube; and this pollen is applied at exactly the right place on her tongue to brush off against the stigmas of a flower of the (*b*) form. While a bee visiting a bluet of the (*b*) form receives the pollen at the base of her tongue, where it is conveniently placed to be brushed off by the protruding stigmas of the flowers of the (*a*) form.

In looking for the two types of flowers among the primroses in the garden, we must not be discouraged if we find them all of the same type because of the way they are artificially multiplied. By perseverance we usually find both kinds.

First and foremost of the devices of the flowers to make the pollen carriers work for them effectively is found in the position of the nectary, which is always placed so that the visiting insect or humming-bird must, in order to reach the nectar, brush against the anthers or stigmas or both during the process. The nectar-producing glands are often found at the bottom of the flowers where the visiting bee must clamber over the stamens and stigmas in order to reach them; however, there is in many flowers a special sac or cup, called the "nectary", which holds the accumulated nectar in safe storage until used; such a nectary may be found in the bottom of the tubular corolla of the petunia or the primrose; sometimes a petal is modified into a nectar sac as in the violet or columbine; and sometimes the sepals may form the sac as in the nasturtium; in all cases the path to the sweet well is barred by anthers or stigmas, and in many instances the depth and shape of the nectary is adapted to a certain kind of insect; the red clover has her nectaries just right for the tongue of the bumblebee to reach; the nasturtium is fitted to be probed by the beak of the humming-bird; while in the case of orchids the forms of the flowers are so changed and specialized that in many instances a partnership exists between one species of plant and one species of insect.

Devices to secure cross-pollination

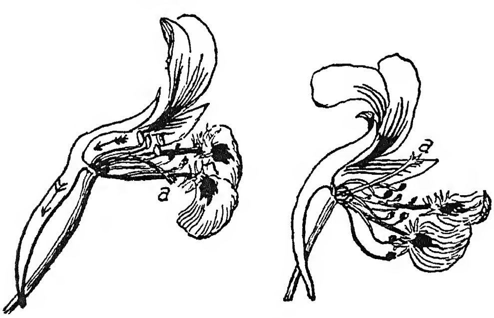
The devices and mechanisms to secure cross-pollination are so many that the flowers of each species seem to have developed some trickery to achieve this benefit. In the nasturtium, five sepals are united at their base and the posterior one is extended into a long spur, — a tube with a nectar-well at its tip. The five petals are set around the mouth of this tube, the two upper ones differing in appearance and office from those below; these two stand up like a pair of fans, and on them are lines which converge; on the upper sepals are similar lines pointing toward the same interesting spot. And what do all these lines lead to, except a veritable treasure-cave filled with nectar! The lower petals tell another story; they stand out, making a platform, or doorstep, on which the visiting bee alights

But it requires a large insect or a hummingbird to do the work of pollinating this flower. If a bee, fly or other comparatively small insect should alight on the petal doorstep by chance and try to steal into the cave, it is prevented entrance by the structure of the flower's lower petals. Each of these lower petals narrows to a mere insect foot bridge at its inner end; and this foot bridge is rendered quite impassable by being studded with irregular little spikes and projecting fringes, sufficient to discourage any small insect from crawling that way.

General Biological Supply House, Inc

Entire flower of the spring beauty, clearly showing the five stamens and the style, split in three parts at the tip

But why all these guiding lines and guarded bridges? If one watches the same blossom for several successive days, it will reveal this secret. When a flower first opens, the stamens are all bent downward, but when an anther is ready to open its pollen doors, the filament lifts it up and places it like a sentinel blocking the doorway to the nectar treasure. Then when the pollinating partner comes, whether it be a butterfly or a hummingbird, it gets a round of pollen ammunition for its daring. Perhaps there may be two or three anthers standing guard at the same time, but, as soon as their pollen is exhausted, they shrivel and give room for fresh anthers. Meanwhile, the stigma has its three lobes closed and lying idly behind and below the anthers; after all the pollen is shed, the style rises and takes its position at the cave entrance and opens up its stigmas, like a three-tined fork. These rake the pollen — from another nasturtium flower — from any visiting insect or hummingbird, thus robbing it of the precious gold dust that will fertilize the seeds contained in the flower's three-lobed ovary and that in this particular manner will assure the continuation of the species.



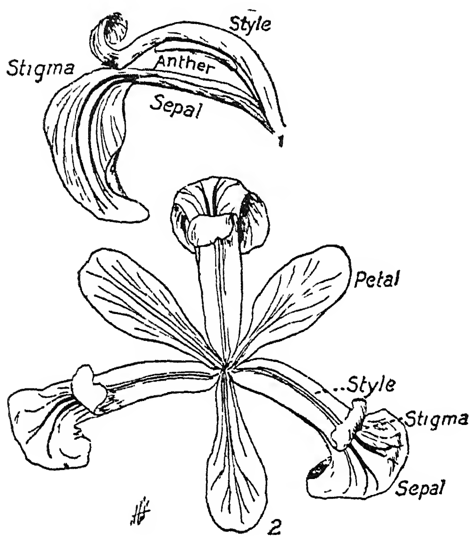
1. Nasturtium flower in early stage of blossoming. The closed stigma is shown deflected at *a*. 2. Later stage; the stigma (*a*) is raised.

The bee larkspur has a similar story except that the beautiful color of its blossoms is entirely in the sepals, and the petals form nectaries and give an alighting place. By their contrasting color they also show the bees where the nectar wells lie hidden.

In barberry and laurel (*Kalmia*), the anthers are held under tension in pockets formed in the petals. The filaments of the stamens are elastic. When an insect alights or bounces on the petal, the petal bends and releases the anther from its position in the pocket. The springing anther dusts the insect with pollen. Stamens and pistils mature, or ripen, at different times to prevent self-pollination.

The iris blossom has a strange appearance, and this is because in it nothing is as it seems. The style of the pistil is

divided into three broad branches and look like petals; they seem to have formed a conspiracy with the sepals to make a tunnel for bees, leaving the petals out of the plan entirely The petals stand up lonely between the three strangely matched pairs, and all they accomplish by their purple guide-lines, is to basely deceive the butterflies and other insects which are in the habit of looking for nectar at the center of a flower. If we look directly down into the flower of the iris, there are ridges on the broad styles and purple veins on the petals, all pointing plainly to the



DETAIL OF THE BLOSSOMS OF THE BLUE FLAG FLOWER

1 Side-view of the passage to the nectar
2 Looking directly into the iris flowers Note the deceiving guide-lines in the petals

center of the flower, and any insect alighting there would naturally seek for nectar-wells where all these lines so plainly lead. But there is an "April fool" for the insects which trust in these guides, for there is no nectar to be had there. Dr. Needham, in his admirable study of the blue flag and its visitors, tells us that he has seen the little butterflies called "skippers", the flag weevils and the flower beetles all made victims of this deceptive appearance; this is evidence that the nectar guide-lines on flowers are noted and followed by insects. In many flowers the opening of the nectary is bordered with contrasting color to show insects the way.

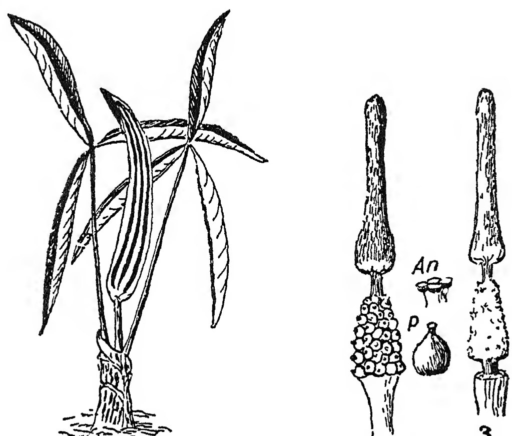
The bee knows where the nectar is

The iris is made for bees; the butterflies and beetles are interlopers and thieves at best. The bees are never deceived into seeking the nectar in the wrong place. They know to a certainty that the sepal with its purple and yellow tip and many guide-lines, although far from the center of the flower, is the sure path to the nectar. A bee alights on the lip of the sepal, presses forward, scraping her back against the down-hanging stigma, then brushes along the open anther which lies along the roof of the tunnel; and here she finds a pair of guide-lines each leading to a nectar-well at the very base of the sepal. The bees which Dr. Needham found doing the greatest work as pollen-carriers for the blue flag were small solitary bees (*Clisodom terminalis* and *Osmia destructa*); each of these alighted with precision on the threshold of the side door, pushed its way in, got the nectar from both wells, came out and sought another side door speedily. One might ask why the bee in coming out did not deposit the pollen from the flower's own anther upon its stigma; but the stigma avoids this by hanging down, like a flap to a tent, above the entrance, and its surface for receiving pollen is directed so that it gathers pollen from the entering bee and turns its back to the bee that is just making its exit.

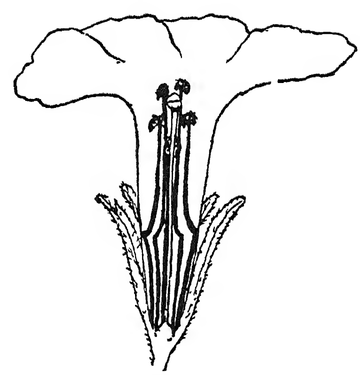
The violet has five sepals and their shape and their length is a distinguishing mark. There are five petals, one pair above, a pair, one at each side, and a broad lower petal which gives the bees and butterflies a resting place when they are seeking nectar. This lower petal is prolonged backward into a spur which holds the nectar. The spur forms the nectary of the violet, and in order to reach the sweet treasure, which is at the rearmost point of the nectary, the insect must thrust its tongue through a little door guarded by both anthers and stigma; the insect thus becomes laden with pollen, and carries it from flower to flower. In many of the species, the side petals have at their bases a little fringe which forms an arch over the door or throat leading to the nectary.

While this is considered a guard to keep out undesirable insects like ants, it is possible that it is also useful in brushing the pollen from the tongues of the insect visitors.

Jack-in-the-pulpit is a near cousin to the calla lily; the white part in the calla and the striped hood over "Jack" are both spathes; and a spathe is a leaf modified for the protection of a flower or flowers. "Jack" has but one leg and his flowers are set around it, all safely infolded in the lower part of the spathe. The pistillate flowers which make the berries are round and greenish, and are packed like berries on the stalk; they have purple stigmas with whitish centers. The pollen-bearing flowers are mere little projections, almost white in color, each usually bearing four purplish, cup-like anthers filled with white pollen. Occasionally both kinds of flowers may be found on one spadix (as "Jack" is called in the botanies), the pollen-bearing flowers being set below the others; but usually they are on separate plants. Often small flies and some beetles carry the pollen for Jack-in-the-pulpit; by crawling about in such narrow quarters they become covered with pollen; and in visiting the next plant, which may bear the pistillate flower, they are sure to be crowded into depositing this pollen on the stigmas.

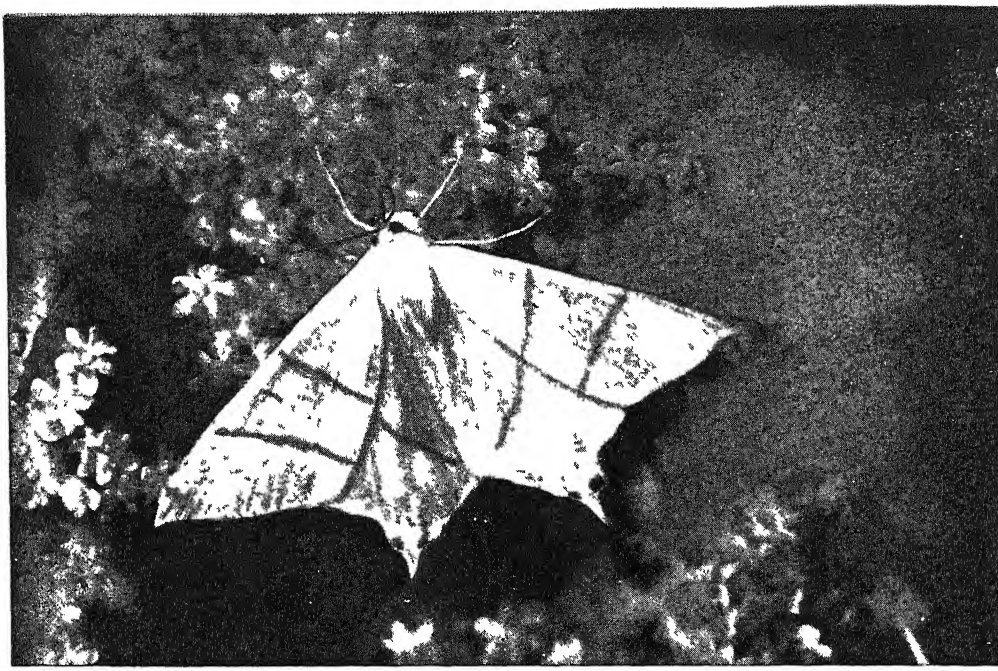


1 Jack in-the-pulpit unfolding, 2 Spadix with pistillate flowers, *P*, pistillate flower enlarged, 3 Spadix with staminate flowers, *An*, a staminate flower enlarged, showing the four anthers



A petunia blossom cut open on the upper side, showing the pistil surrounded by the incurved stamens and the partially opened stigma surrounded by the anthers Note the short stamen below the pistil

When a petunia flower first opens, there lies near the bottom of the throat of the tube the green stigma, with two anthers snuggled up in front of it and two behind it, the latter being not quite so advanced in age as the former. As the filaments of the front pair of anthers are longer than those of the rear pair, the little group lies at a low angle, offering a dusty door-mat for entering insects. If we open a flower at this stage, we find another anther, as yet unopened, and which is on the shortest stamen of the five. This seems to be a little pollen-reserve, perhaps for use later in the season. There is an interesting mechanism connected with these stamens; each is attached to the corolla-tube at the base for about half its length, and at the point of attachment curves suddenly inward so as to "cuddle up" to the pistil, the base of which is set in the nectar-well at the bottom of the flower. If we introduce a slender pencil or a toothpick into the flower-tube along the path which the moth's tongue must follow to reach the nectar, we can see that the stamens, pressing against it at the point where they curve inward, cause the anthers to move about so as to discharge their pollen upon it; and as the toothpick is withdrawn they close upon it cogently so that it carries off all the pollen with which it is brought in contact. If we look at the



A MALE SWALLOW-TAIL MOTH SUCKING NECTAR, BY MEANS OF ITS LONG TONGUE, FROM THE DEPTHS OF AN ELDER-FLOWER

stigma at the center of its anther-guard, it has a certain close-fisted appearance, although its outer edges may be dusted with the pollen; as the flower grows older, the stigma stands above the empty anthers

THE LITTLE ANDRENA BEE POLLINATING THE MOCCASIN FLOWER

at the throat of the flower tube and opens out into two distinct lobes. Even though it may have accepted some of its own pollen, it apparently opens up a new stigmatic surface for the pollen brought from other flowers by visiting insects.

In the case of the moccasin flowers, which are among our most attractive orchids, we find a most interesting condition. The two sepals and the two side petals are formed into streamers to attract attention to the lower petal, which is made into a puffed-out sac; this sac opens above with its edges incurved, the coloring of the edges makes it a most enticing place for little bees to visit and when a bee once crawls into the sac, the recurved edges keep it prisoner; at the bottom of the sac there are delectable vegetable hairs to be browsed upon although there may be no nectar. Soon the bee, in trying to escape, sees light through two little openings near the stem quite away from the door by which she entered; extending out into each of these openings is an anther, but it is a very peculiar anther, for as she crawls up past it in order to get out, her back presses against it and becomes smeared with the pollen as if it were made into a plaster, and she still wears this pollen plaster when she visits the next flower and, in getting out of that one by the little side door. she scrapes it off upon the stigma

which she has to push against in order to get out and she may, from this flower, after having passed the stigma become smeared with another pollen plaster.

Such stories as those mentioned are limited in number only by the flowers studied, since each one has its own to tell to eyes keen enough to see. The bleeding heart, the sweet pea, the columbine, the sage, the hollyhock, the laurel all have very interesting devices for securing cross-pollination and the composites have an equally wonderful array.

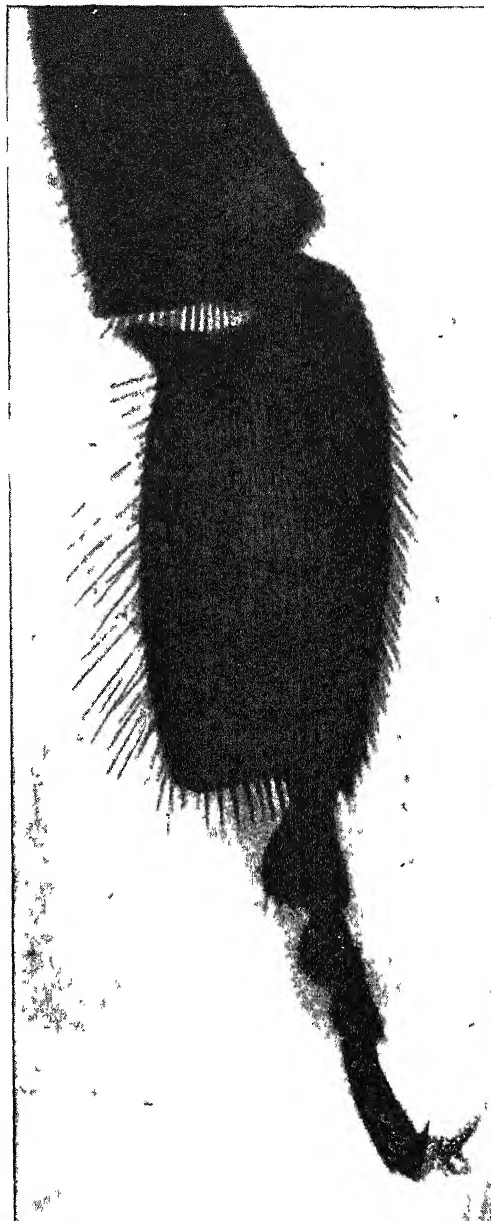
How the flowers save their pollen when the carriers are not around

The most readily observed device of flowers to save their pollen is the closing of flowers during storms, dark days and nights and so protecting their pollen when their insect pollen carriers are not flying abroad. The hepatica closes its petals and hangs its head during a snow storm; the dandelion does not open until late in the morning and closes early in the afternoon; the tobacco flower opens in the evening when the sphinx moth is flying; so also do the petunias, which depend on the sphinx moths for carrying their pollen. The evening primrose flares its petals wide in the late afternoon at the time when its special moth partner is active. There are too many instances like these for mentioning.

How unbidden guests are kept away from the laden board and flowing cup

Flowers are quite as clever in their devices to keep unbidden guests from sharing their pollen and nectar. Such arrangements are found in flowering plants in abundance, and mostly they take the form of some method of carefully guarding the entrance to the nectary, or the spot where the nectary lies. All sorts of structural obstacles are developed by plants for this purpose, but most of them have this in common — that, while they are quite strong enough, and effective enough, to prevent small insects forcing them apart, they are not of such size or strength as to interfere with the larger ones.

This partnership with flowers has had as profound an effect in changing the form of the insect as it has in the case of the



THE HIND LEG OF THE WORKER BEE

This micro-photograph shows, above the claws and pads of the foot, the pollen brush, consisting of rows of stiff hairs, and above it the pollen basket, also provided with strong hairs

flower. The bees are the most important of all the pollen carriers because they pollinate more of our flowers than do all of the other agencies combined. The bees

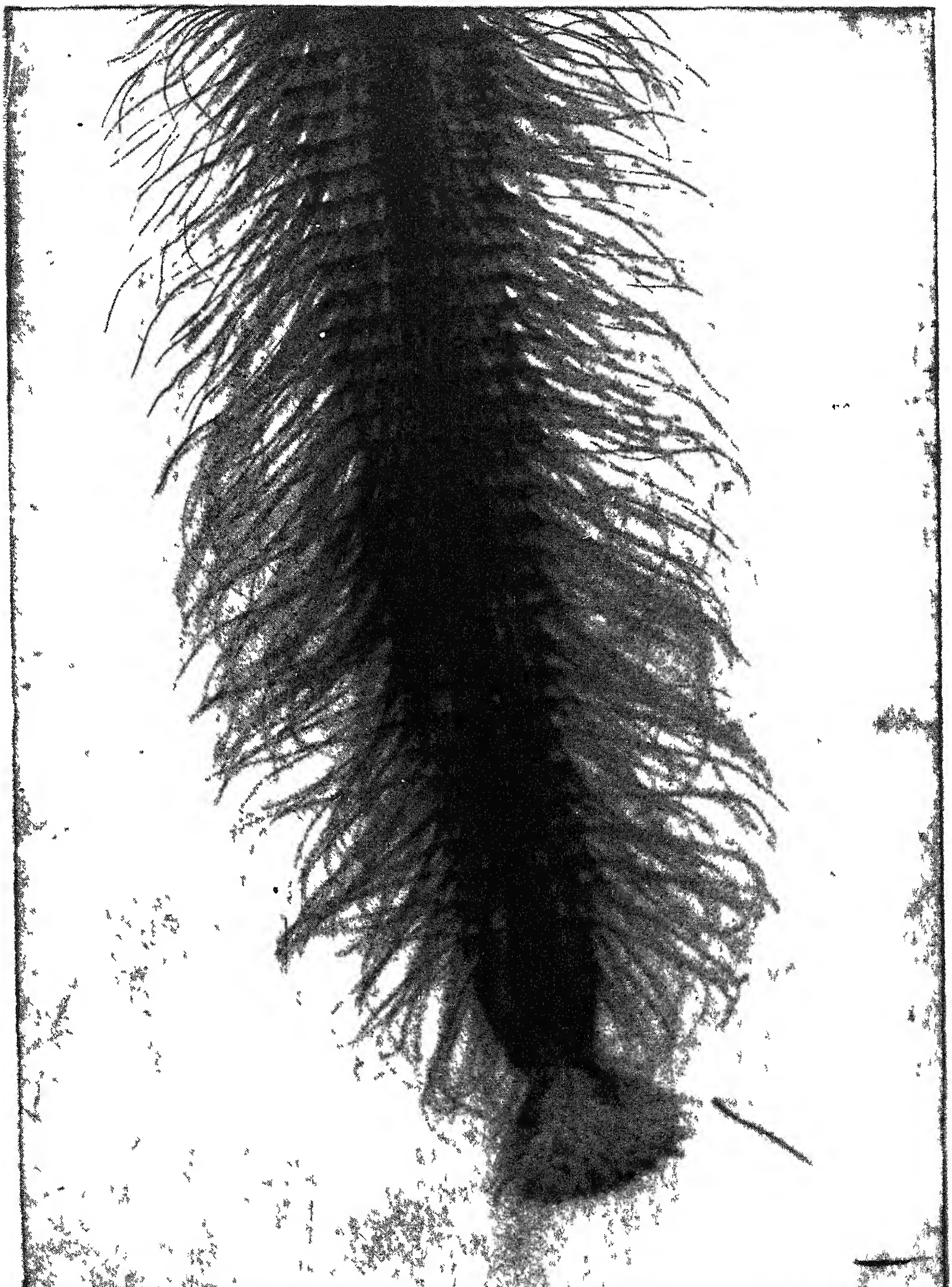
are like man, they think the world was made for them because they have been able to put so much of it to their own use. While there are a very large number of flowers that have nectaries especially fitted for their convenience, yet the bees will try to work in any flower not meant for them, such as nasturtium, scarlet sage and columbine, which were obviously meant for humming-birds or butterflies; they will squeeze in where they are not invited, but it may be said for them that they are efficient pollen carriers even for these flowers which do not invite their visits, moreover many of the flowers that do not have nectar are cross-pollinated by the bees; such is the case of the hepaticas, the poppies and many others. Pollen is a very important element in the food of the young bees, being the flour of which bee-bread is made. To gather this pollen the honey-bee has a hairy body like a brush so that she brushes off all the pollen which she touches. She has on the first joint of the foot on her hind leg rows of stiff hairs which she uses to comb the pollen out of her fur and pack it into her pollen baskets which are situated on the upper side of this same segment. On her middle leg she has at the tip of the tibia a long spur developed purposely to push the pollen out of her pollen baskets into the cell of the honeycomb. For securing nectar she has a long tongue fitted for sucking; she has also a special stomach quite separate from her own food-digestive stomach in which the nectar which she gathers from flowers is changed chemically and made into honey. The bumblebees and all the other social bees have been changed in a similar manner. The little solitary bees, which do a great work for our early wild flowers especially, may carry their pollen packed among hairs on their legs or those on the under side of body. They have all been modified in form to make them more efficient as pollen carriers.

ONE OF THE TUBES OF A BUTTERFLY'S TONGUE, PARTLY UNCOILED

Not only have the bees been changed in form to make them more efficient as pollen carriers, but they have developed habits which are also most useful. The chief of these is the habit of working on the same species of flower and none other at certain seasons or times of day. For instance, when a bee is finding nectar in the larkspur she goes from larkspur to larkspur and pays no attention to any other flowers; and when she is gathering pollen from poppies she pays exclusive attention to those bright blossoms and ignores all others. Thus the bee lives up to her obligation and does not bring the pollen of one species of plant to the stigmas of another.

The moths and butterflies have been much modified also by their partnership with flowers; in their case one pair of jaws has been greatly prolonged, each jaw being grooved on the inner side, and the two being joined together lengthwise form a long tube through which nectar is sucked; this long tongue is carried coiled in a spiral when not in use.

THE ORGAN WITH WHICH THE BEE SUCKS

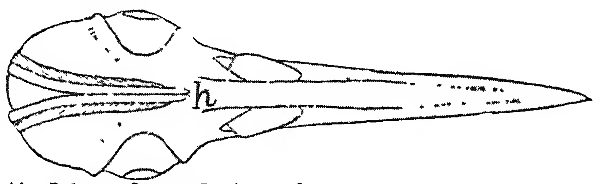


The proboscis or tongue of the honey bee—of which the end portion is shown here highly magnified—is a hollow organ filled with fluid and terminating in a "bouton" or spoon. The nectar gathered from a flower by the bouton passes up the flexible under surface of the tongue in a groove, which is surrounded by thickened skin and formed into a tube by numerous fine hairs. The nectar then enters the pharynx, and passes, mixed with saliva, into the honey-bag, where it is changed into honey.

The photographs on these pages are by Mr. J. J. Ward and Messrs Hinkins and Son.

The butterflies frequent the deep-throated flowers that open by day, and the moths visit those which open in the evening The sphinx moths are quite the most efficient of all the moth family as pollen carriers In the case of the butterflies and moths the fringes and scales and hairs around the base of the tongue brush off the pollen from the ripe anthers and carry it to the awaiting stigmas

The hummingbird has also been changed in form so that it is a most efficient pollen carrier for deep-throated flowers, especially those native to tropical and sub-tropical countries where there are many species of hummingbird. This bird has a beak and tongue especially fitted for sucking the nectar while it hangs poised on its whirring wings in front of its flower partner. It also befriends the flowers in another way, for it takes all of the little insects which it finds stealing the nectar and uses them as a part of its diet. Its tongue has the outer edges curved over on each side thus making double tubes; and these tubes are provided with minute brushes at the tips adapted for sweeping up the insects.



After Ridgeway, Courtesy Smithsonian Institution

HEAD OF A HUMMINGBIRD (*EULAMPIS HOLOSERICUS*)

Seen from above and showing the termination of the hyoid or tongue bones (*h*) The shaded bands indicate the muscles which retract the tongue Figure is twice the natural size

When our interest is once aroused in this wonderful and complex partnership between flowers and their pollen carriers, we find a new pleasure in every walk in the garden, woods or fields. Everywhere we may study for ourselves these partnership secrets and adaptations, and even in the most common flowers we may discover things as yet unknown to scientists Moreover, in this study we learn a sweeter lesson than that enforced upon us when we view the natural world as a battle-field in which the "fittest" win victories by exterminating the great "unfit"; for here we can see that the fittest have survived and made good by happy cooperation instead of by fierce and cruel competition.

THE ROLE ENACTED BY CELLS IN THE ORGANIZATION AND GROWTH OF THE BODY

by

HUGH DANIEL REED, Ph.D.

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WHEN the word "cell" is employed in the usual linguistic sense, a reference is made to walls which surround and delimit any given space regardless of what is contained within the walls (Fig. 1a). In a biological sense the term refers to the contents with the walls removed as it were. That is to say, protoplasm, the ground substance of the body, is everywhere divisioned off in the form of these minute (microscopic) masses called cells. The protoplasm limits itself without any extraneous materials formed as a cell wall. Protoplasmic cells do not possess walls. This concept is illustrated by Figure 1b. All body substance is comprised of cells and materials representing the products (e. g. bone) of their activities The animal body is, therefore, said to be multicellular in its structural nature and the cell has come to be regarded as the structural and functional unit in the body. Some conception of the cellular nature of body substance may be gained by reference to Figure 2 which schematically represents a minute piece of membrane which might be taken as a smooth homogeneous sheet of body substance When viewed with suitable magnifying powers what otherwise appears as mentioned is found to be formed of these microscopic units, fitted together to form the membrane.

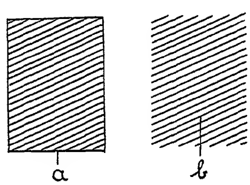


FIG I. DIAGRAMS ILLUSTRATING WHAT IS MEANT BY THE TERM "CELL", A, IN THE USUAL SENSE WHERE REFERENCE IS MADE TO WALLS ENCLOSING SPACE, AND, B, THE BIOLOGICAL SENSE WHERE THE REFERENCE IS TO A MINUTE MASS OF PROTOPLASM LIMITING ITSELF WITHOUT WALLS

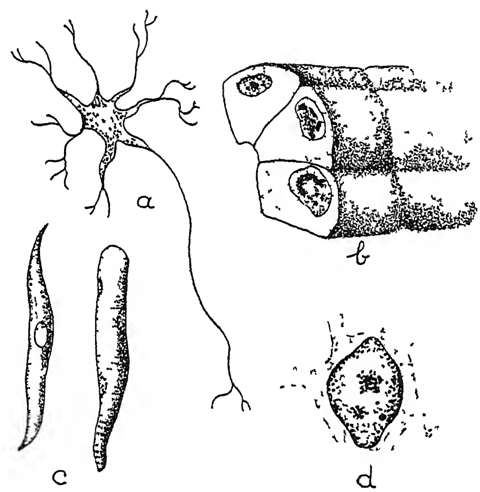


FIG 2 REPRESENTATIVE CELLS OF THE FOUR PRIMARY TISSUES A NERVE CELL, B EPITHELIAL CELLS, C MUSCLE CELLS, D, INDIFFERENT CONNECTIVE TISSUE CELL

There are no cells visible to the unaided eye and one may correctly infer that almost incomprehensible numbers of these organized particles of protoplasm are necessary to form a body as large as that of the average man. It has been estimated that in man there are a billion cells to each cubic inch of body substance.

The cells of the body instead of remaining alike come to be of different kinds. Whatever may be at the bottom of this differentiation is of no import at present; the fact remains that they differ from one another, thus laying the foundation for their grouping into aggregates called tissues. For the present study a tissue may be defined as an assemblage of cells similar in organization and function. Thus as a result of becoming different there are formed four primary assemblages of cells or tissues, (1), *epithelial* or cover tissue, the cells of which form membranes covering all exposed surfaces and lining all internal cavities (Fig. 2b); (2), *connective, binding*, and *supporting* tissues, the general functions of which are reflected in the name (Fig. 2d); (3) *muscular tissue* devoted to the production of movements of the body or its parts (Fig. 2c), and (4), *nervous tissue* concerned with communications of one part with another (Fig. 2a). In each case the tissue is formed of cells and their products.

Since the cells of the body remain microscopic in size there is suggested the general inference that increase in the size of cells does not account for the increase in the size of the body. When this inference is followed by actual observation it is found that each tissue of each kind of animal does not vary widely with regard to the maximum size of its cells. Growth of the body (increase in size) then cannot be accounted for by an increase in the size of its component cells. Spontaneous generation and the importation of cells from the outside do not occur, as studies of living things have revealed. Cells come into being because other cells have lived before them and have given rise to them. One must look to the multiplication or reproduction of the cells themselves as the explanation of their increase in numbers either as components of a given animal body or as independently living cells. The only method by means of which cells may reproduce is that of the division of a mother cell into daughter cells. The mother cell (as such) ceases to exist but continues to live in the form of daughter cells. *Cell division* may, therefore, be used as a name expressing the nature of cell multiplication which provides for an increase in the amount of body substance.

Before making an attempt to relate the phenomena attending cell division it will be necessary to inquire into the organization of a generalized cell.

The cell is not so simple as the remarks made above might indicate. One finds that the protoplasm in the cell is organized in a complex manner. Many times reference is made to what is termed a *typical* cell. Such a cell does not exist. They vary within wide limits. Attention will be called to those organized portions which one encounters in all cells. The protoplasm of the cell is divided into two great regions; one more or less compact and located near the center, called the *nucleus* (Fig. 4) and a mass of protoplasm between the nucleus and the margin of the cell called the *cytoplasm*. The nucleus varies in form and position in different cells. It may be found near the middle of the cell (Fig. 4) or excentric in position (Fig. 2b). The parts of the nucleus are important, as will be seen in the latter part of this study. In the first place, the nucleus is set off from the rest of the cell by a portion of its own protoplasm serving as a membrane which is accordingly known as the *nuclear membrane*. This is not only a region of protoplasm surrounding the nucleus but it discriminates in respect of the substances which may pass in either direction. Scattered through the protoplasm of the nucleus there are irregular threads interrelated in an intricate manner, and called the *linin network* (Fig. 4). Upon the threads of this network there is a certain protein material arranged in the form of droplets. Because of its chemical nature the substance of these droplets possesses a special affinity for certain kinds of dyes, and it is, therefore, known as *chromatin material*. Another portion of the nucleus which is conspicuous is a compact area which seems to be set off from the rest of the nucleoplasm and termed the *nucleolus*. Filling the spaces about the chromatin particles and nucleolus there is a more liquid protoplasm that is known as the *nuclear sap*. The importance of the nu-

cleus in the cell may be summarized as follows: first, it is in control of constructive activities, such as the building up of new protoplasm or stores or the elaboration of secretions; and, second, certain nuclear materials are important in heredity.

All the rest of the protoplasm of the cell is the cytoplasm. There is no cell wall. At the surface, however, there is a dense stratum of protoplasm which functions as a membrane and may be known as the cell or *plasma membrane*. As a discriminating envelop it is similar in every respect to the nuclear membrane. The general services rendered by the cytoplasm are such as destructive changes accompanied by energy transformations. It serves as a medium for eliminating materials that must be passed on to the outside, and it serves also by way of receiving and altering materials needed within (e. g. food).

As stated above it has been determined by observation that the cells of any given tissue do not increase in size beyond a certain point and that an increase in body size is due to the increase in the numbers of component cells. Everything that is known about living organisms precludes the possibility of explaining this situation in any other manner than that of cell division, which may be taken as a general statement applying to the increase in cells in any multicellular organism. There are two methods according to which cells may divide, and the almost universal method is known as *mitosis*, or *indirect cell-division*. The application of the name will become apparent later. Whenever growing tissue is examined microscopically one obtains such pictures as are illustrated by Figure 3, cells a and b. These cells are in the process of division according to the mitotic method. Rather than dividing directly the cell passes through a series of changes in preparation for the actual division into two daughter cells which has suggested

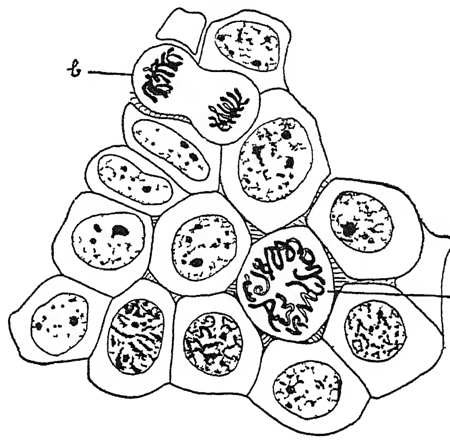


FIG. 3. SECTION OF THE OUTER SKIN OF A GROWING ANIMAL CELLS EXHIBITING SUCH FIGURES AS A AND B ARE IN THE PROCESS OF DIVISION.
Redrawn from Edmund B Wilson's *The Cell in Development and Heredity*, by permission of The Macmillan Company Publishers

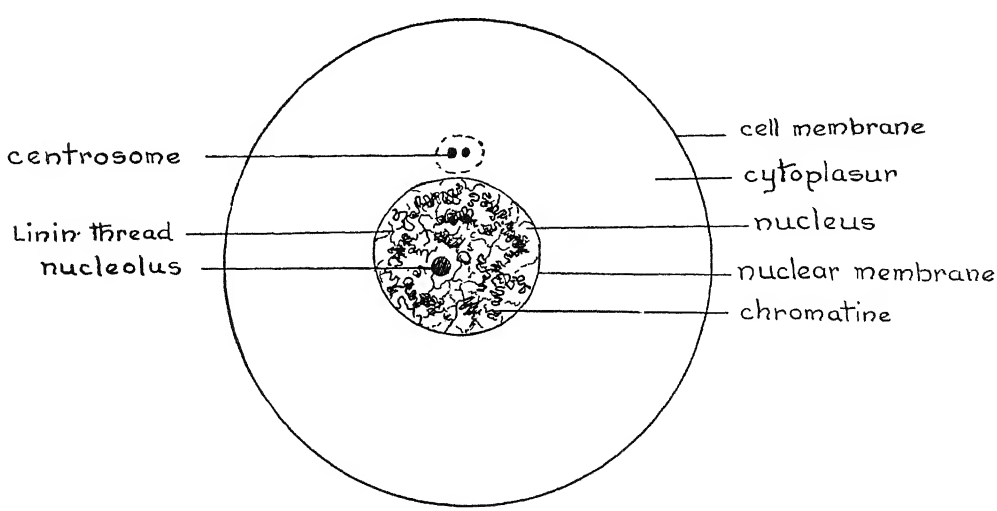


FIG. 4. DIAGRAM OF A CELL WHICH IS INACTIVE AS REGARDS DIVISION.

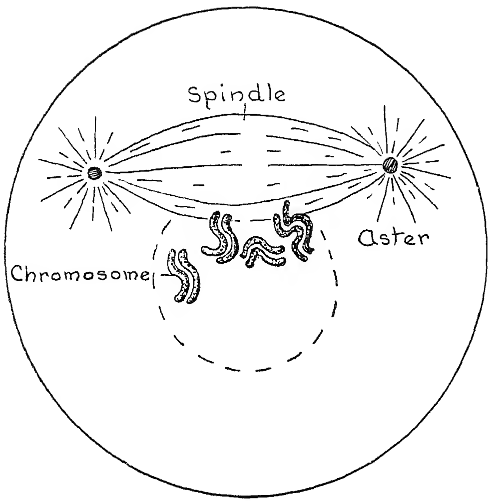


FIG. 5. DIAGRAM OF A DIVIDING CELL WHICH HAS REACHED THE STAGE OF CHROMOSOME FORMATION AND SPLITTING INTO DAUGHTER CHROMOSOMES. THE SPINDLE AND ASTERS ARE CONSPICUOUS, THE CENTRAL BODIES ARE MIGRATING APART AND THE NUCLEAR MEMBRANE IS DISAPPEARING.

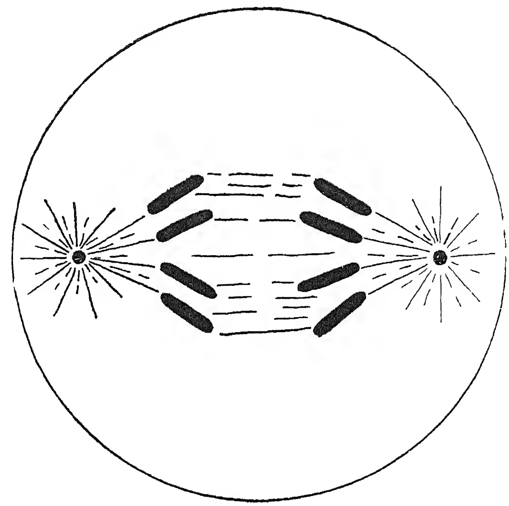


FIG. 7. DIAGRAM OF THE MIGRATING CHROMOSOMES TOWARD THEIR RESPECTIVE POLES, AND THE REDUCTION OF THE SPINDLE.

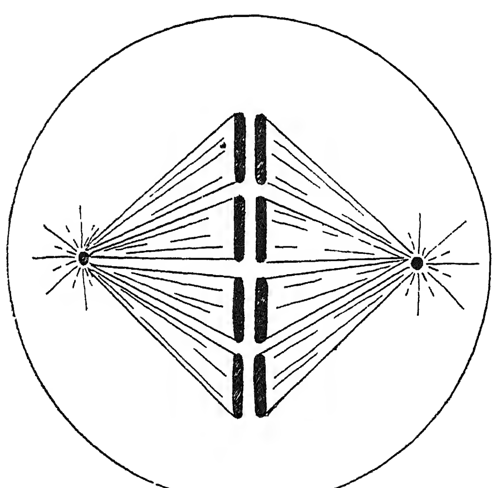


FIG. 6. DIAGRAM OF THE ARRANGEMENT OF THE DAUGHTER CHROMOSOMES, STILL IN PAIRS, TRANSVERSELY TO THE SPINDLE FIBERS AND IN THE EQUATORIAL PLANE OF THE CELL.

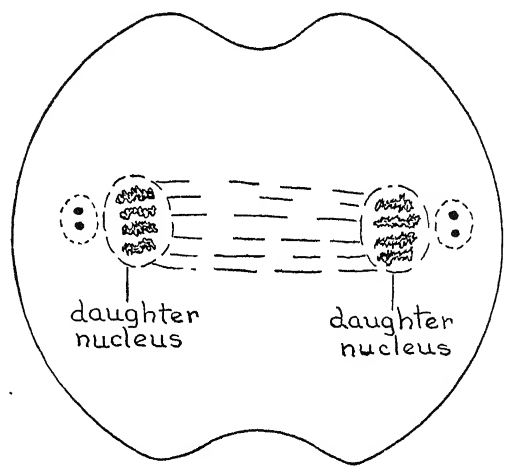


FIG. 8. DIAGRAM OF THE REORGANIZATION OF DAUGHTER NUCLEI IN WHICH PROCESS THE DAUGHTER CHROMOSOMES, ONE FROM EACH PAIR, PARTICIPATE. THE CENTROSOME OF EACH POLE HAS DIVIDED.

the term "indirect cell-division." It is in connection with these preparations for the final division of the protoplasm that most of the significant phenomena are encountered. It will be found that the nucleus is very intimately concerned with the preparations for final division. and especially the chromatin material. The process of mitosis is illustrated by Figures 4-9. Figure 4 may be taken as an illustration of a cell not actively engaged in division at the moment. It should be borne in mind that cell division is always a continuous process.

Each of the figures illustrating mitosis should be taken as representing the culmination of events at the stage each represents. Mitosis does not proceed by leaps.

The study of a vegetative cell (Fig. 4) reveals the chromatin material arranged in an irregular network. Just outside the nucleus and lodged in the cytoplasm are two minute but compact bodies called the *centrosomes* or central bodies. Surrounding them is an area of protoplasm which is readily recognized as differing from the adjacent cytoplasm. The paired centrosomes are formed by the division of a single body. Starting with this state of affairs within the cell, early progress toward division is that shown in Figure 5 where the two cetnral bodies have moved apart; that is, each has moved towards its own pole of the cell. An area of protoplasm between them has become arranged as strands which appear to come to a focus at the separated centrosomes. The fibril-like strands thus assume the form of a spindle, by which name the figure is known. At the same time radiating strands of protoplasm are arranged about each centrosome causing it to appear star-like. Each is therefore known as an *aster*. During the progress of spindle and aster formation other noticeable and important changes have taken place. The chromatin material has become consolidated and resolved into definite bodies each of which is called a *chromosome*. It is to be noted that the nuclear membrane has lost its identity and the nucleoplasm and cytoplasm are mingled. While the chromatine network is being resolved into definite chromosomes it passes through a stage in which it forms a complex of coiled threads (Fig. 3a). This suggested the name "mitosis" which means "thread."

Every species of animal possesses a definite and constant number of chromosomes in every cell of its body. Some species possess a small number of chromosomes, in others they are numerous, while others range between the two extremes. The accompanying illustrations assume that four chromosomes are present in each cell.

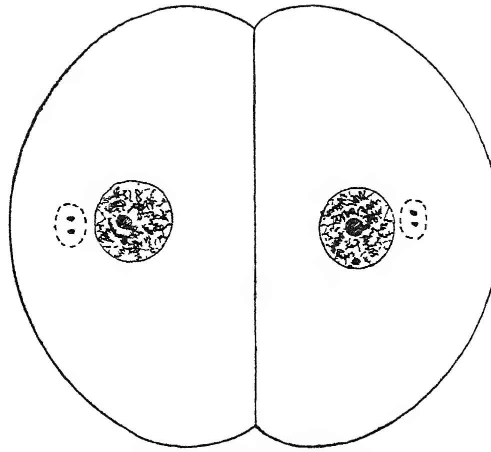


FIG. 9. DIAGRAM OF TWO NEW DAUGHTER CELLS FORMED BY THE DIVISION OF A MOTHER CELL AS THE CONCLUDING STAGE OF MITOSIS.

During the period in which the chromatine and other materials are being resolved into distinct chromosomes a most important feature of behavior is to be observed in these bodies. They split longitudinally throughout their entire length, thus forming four pairs of chromosomes (Figs. 5 and 6). Each of the four splits into two, so that actually at this phase there are eight distinct chromosomes, each pair representing daughter chromosomes arising from the division of a given mother chromosome. The nature of this division is important. If one were to consider that each chromosome is comprised of a definite number of particles arranged in a linear series at the time of splitting (see Fig. 10, A, and aa) they do so through the

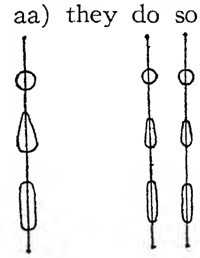


FIG. 10. DIAGRAM TO ILLUSTRATE THE EQUAL QUALITATIVE AND QUANTITATIVE SPLITTING OF A CHROMOSOME.

middle of every component particle, so that in the completed division two chromosomes "a" and "a" resulting from the division of "A" would possess these particles arranged in the same order, and both

chromosomes would be alike in every respect That is, during the splitting process of the chromosomes there comes about an equal qualitative and quantitative division of the chromosome material.

During this part of the process, which may be referred to as the formation and splitting of chromosomes there occurs a stage in which the central bodies have reached their respective poles of the cell and cease to migrate farther apart. The two halves of the original chromosomes remain together as a pair and come to be arranged in a plane midway between the two central bodies. This is said to be the *equatorial arrangement* of the chromosomes. Wherever they may have been previously lodged they come into this arrangement. They take positions transversely to the fibrils of the spindle, some of which appear to come into direct contact with the chromosomes. This state which is represented in Figure 6 is one in which there is no activity with regard to division. It appears as though the chromosomes were held in a state of balance between two opposing forces. If the chromosomes have not split by the time they reach this position they do so then. This is a short, apparently inactive phase in the progress of cell division.

Following the equatorial arrangement the halves of the chromosomes separate, each moving toward its own pole of the cell (Fig. 7). This continues until the spindle is very much subdued as are the astral rays also. Finally the chromosomes reach the opposite poles of the cell (Fig 8) The spindle and asters disappear. Each central body divides into two as if in anticipation of the next role it is to play in cell division. The chromosomes become less distinct and gradually assume the form of an irregular network of chromatin material. A nucleolus and nuclear membrane appear. Two daughter nuclei are finally organized out of the chromosomes which split, and come to be located in what later become two new daughter cells (Fig. 9). Along with the nuclear reorganization the cytoplasm becomes constricted midway between the new nuclei. This constriction deepens until the cytoplasm is divided and two daughter cells have resulted from the division of a mother cell (Fig. 9). The daughter cells grow to the proper size and in their turn divide,—and so the process goes on within the body.

The details related in the foregoing paragraphs, when read from the standpoint of the factual, lose much of their value. The utility of such facts is realized only when reviewed in the light of their significance. That is, what is the advantage to the organism of a multicellular body to which new bulk is added through cell reproduction and growth? The answer may be outlined as two separate items. First, an active body requires that food and oxygen be taken to all regions and into body substance itself. The transportation must be accomplished quickly. This is particularly true in the case of oxygen transportation since it cannot be stored against a time when the supply might fail. Thus one sees the advantage of constant respiration and the results if the organism is prevented from breathing longer than a brief interval. If the body were a homogeneous mass diffusion of materials into and out of body substance would be too slow to meet the needs. Body substance being divisioned off as minute mass or cells the diffusion of materials is rapid and sufficient. Second, division by mitosis results in an equal qualitative and quantitative division of the chromatin materials. Every chromosome in every cell has the same equipment of nuclear material. The nuclei in all cells are therefore alike and may produce cells like themselves. The disappearance of the nuclear membrane promotes the merging of nuclear material and cytoplasm which may be regarded as a process of invigorating the cytoplasm which eventually forms that of the daughter cells. The proper ratio between the surface and mass of the cell is maintained by division. Everything in the way of inner cell activity is provided for by the surface. Since the mass increases more rapidly than the surface there would come a time when the surface would be unable to support the mass. With the division of the cell the proper ratio of mass and surface in the daughter cells is restored

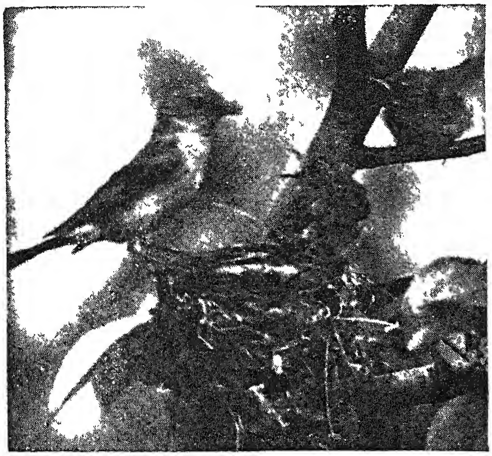
MULTIPLICATION BY DIVISION

Photos courtesy New York Scientific Supply Co.

TWO STAGES IN CELL DIVISION

These photomicrographs show onion root cells magnified 1600 times. The earlier stage, shown by the center cell in the top photo, is known technically as the anaphase, while the later stage, shown in the bottom photo is the telophase.

SOME MEMBERS OF THE WARBLER FAMILY



FEMALE REDSTART, NEST AND YOUNG

MALE CHESTNUT-SIDED WARBLER GUARDING NEST

FEMALE MARYLAND YELLOW THROAT INCUBATING

YELLOW WARBLER AT ITS NEST

FEMALE CHESTNUT-SIDED WARBLER BROODING

A BOLD BLACK-AND-WHITE WARBLER AT ITS NEST

A BRAVE BLACKBURNIAN WARBLER ON ITS NEST

The illustrations in this chapter are from photographs by A. A. Allen.

OUR COMMON BIRDS II

The Warblers, Vireos and Waxwings, Shrikes and Swallows

WOODLAND WARBLERS AND GRACEFUL SWALLOWS

PERHAPS no family of birds plays a greater part in the protection of our forests than the warblers (family *Mniotiltidæ*). Being primarily woodland birds, they arrive in the spring when the leaves are just beginning to unfold and the hordes of caterpillars are emerging from the eggs in which they have passed the winter. Not a twig goes unnoticed, scarcely a bud unscrutinized as this army of busy travelers sweeps on to its northern breeding ground. During April, May and June when the migration is in progress, they practically rid the trees of insect pests which otherwise would defoliate them. But besides this economic appeal they have an æsthetic one, and certain it is that no group of birds is more attractive to the beginner in bird study than these multi-colored, active forest-dwellers. At first they baffle him with their great variety of colors and rather nondescript songs but they lure him ever to more persistent effort by challenging his perseverance.

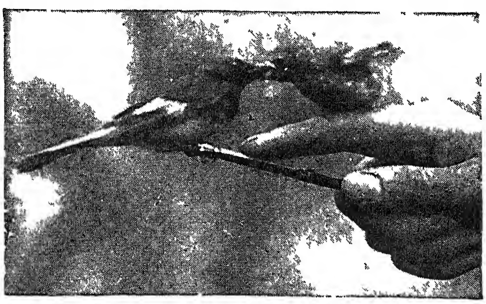
The warblers are one of the larger families of birds, containing about one hundred and fifty-five species confined entirely to the New World. In summer they stretch from northern Alaska to Argentina, but only about fifty-five species visit the United States. Forty species are confined to South America, thirty to Central America and Mexico, twenty to the West Indies and ten to the Galapagos Islands. Each species is characteristic of some particular region. Thus, after they have settled down for the summer, we find that certain species never nest north of Virginia, others never south of New York or Pennsylvania, and others always north of the United States' boundary. Each species is characteristic also of some particular habitat; the oven-bird and water-thrushes are terrestrial, the Kentucky blue-winged and chestnut-sided warblers and chats are birds of the undergrowth; while the blackburnian and yellow-throated warblers confine themselves largely to the tree tops.

Since all the warblers are insectivorous, they are, perforce, highly migratory, seeking southern climates when the insect supply is exhausted in the north. At the approach of winter some species go only to southern United States for the winter, and the myrtle warbler, which is rather an exceptional species, and perhaps the hardiest of all, winters often as far north as southern New England, changing its diet to one of bayberries. The shortest journey which any blackpoll makes, on the other hand, is thirty-five hundred miles, while those that nest in Alaska probably travel even a thousand miles farther every year to their winter home in Brazil. Nearly all the warblers of the western United States spend the winter in Mexico and northern Central America.

It might be expected that those species which migrate to South America would follow the island chain of the West Indies, keeping thus to landmarks, but such is the case with only a few species, the majority preferring the direct flight of five hundred miles across the Gulf of Mexico. They migrate mostly at night, although they continue their journey slowly during the day, feeding as they go. Occasionally they make long flights across bodies of water by day, but usually this is done at night.

What guides them on these journeys may always be a mystery, but it is now thought that birds have a special and very highly developed "sense of direction". Ordinarily they migrate from a few hundred feet to nearly two miles above the earth, but on cloudy nights they descend to escape the clouds and then often become confused by the illuminations in lighthouses or tall buildings and dash themselves to death against the glass. Several hundred birds, a large percentage of them warblers, have been picked up at the foot of a lighthouse, the Washington Monument and similar places after a foggy night.

As might be expected, the first warblers to push northward in the spring are those which are the hardiest and whose migration routes are the shortest. Thus the pine and the myrtle warblers arrive in northern United States while the trees are still bare, and the blackpolls do not begin to arrive until the middle of May. In the fall the redstarts and yellow warblers start back before August while insect food is still most abundant, but the myrtles and others of short migration routes remain until the leaves have fallen.

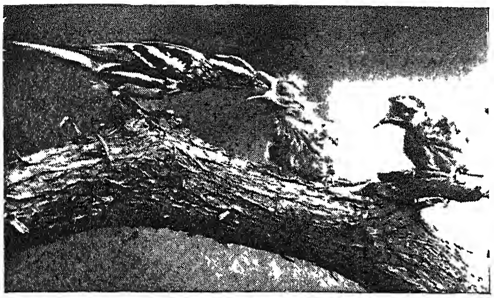


A FRIENDLY MALE REDSTART FEEDS ITS YOUNG

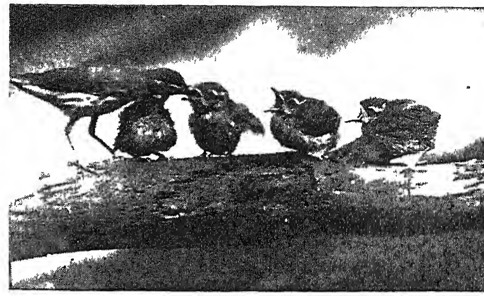
It might be expected from the name of the family that these little birds are beautiful singers. The truth is, however, that there are very few whose songs are much more musical than the calls of insects. A few whose songs are weak make up in sweetness what they lack in volume. The water-thrushes with their wild, ringing notes, the chat with its loud, bizarre calls and whistles, the ovenbird with its varied flight song are perhaps exceptions. The simple trill of the yellow warbler, the wheezy notes of the black-throated blue, the insistent calls of the Tennessee and the blackpoll, the vivacious notes of the redstart and the chestnut-sided warblers fix themselves readily in one's mind, but many of the warblers' songs are a combination of various of these sibilant wheezy or trilling syllables, so that the discovery and identification of the warblers, until once the songs are learned, is difficult.

The nesting habits of warblers are as varied as their colors and present many surprises. Most birds nest where they find their food, so that one expects terrestrial birds to nest on the ground and tree-loving birds to nest in the tree tops. One is not surprised, therefore, to find the nests of the ovenbird and water-thrush on the ground, those of the chestnut-sided warbler and the chat in the low bushes, and that of the blackburnian warbler in the top of an evergreen. It is strange, however, to find the black and white warbler, which spends its life creeping about the trunk and larger branches of trees, descending to the ground to nest as do also the Nashville and Tennessee warblers, which we find most frequently singing in the tree tops. The roofed-over nest, which gives the ovenbird its name, the lichen-covered nest of the cerulean warbler, and the cottony cradle of the yellow warbler are perhaps the most unusual of the warblers' nests, the majority being made of grasses, rootlets, leaves and other common materials woven into the ordinary cup-like form. The eggs of the warblers are remarkably uniform, being creamy white, more or less spotted with brown, and it requires ten or eleven days for them to hatch. The young remain in the nest from eight to twelve days but are cared for by their parents for some time thereafter, since only one brood usually is raised in a season.

To the warblers is given the care of the foliage of the trees and therefore the good health of the forests. They are the tree doctors just as the woodpeckers are the tree surgeons. As long as the foliage is kept in good condition the trees will be healthy and produce good wood. Conifers will scarcely stand a single defoliation and deciduous trees are seriously devitalized even by a



MALE BLACK-AND-WHITE WARBLER FEEDING ITS YOUNG



LOUISIANA WATER-THRUSH (A WARBLER) FEEDING ITS YOUNG

single stripping of the leaves. Never a year passes when sufficient caterpillars are not hatched to defoliate every woodland in this country, so prolific are the moths which lay the eggs. It is perfectly possible nowadays to spray the shade trees of city streets and thus protect them from these pests, but for the woodlands we must continue to rely upon the protection which birds give. Chief among these arboreal guardians are the warblers, and the thoroughness with which they do their work can be proved by anyone who will observe a tree infested with the canker worms, aphids, gipsy moths or almost any other pest. Once the migratory troops of warblers discover it, they will remain about it for days, new birds frequenting it all through the migration season, until the caterpillars become so scarce that they are difficult to find. The number consumed by a single bird seems almost incredible, but most careful and accurate information has been accumulated, giving actual numbers consumed, which attest the tremendous economic importance of this family.

The Vireos

The vireos (family *Vireonidæ*) are not brightly colored birds but they wear greens, grays and yellows in modest, pleasing combinations. Although not much larger than their brightly colored congeners, the warblers, they move about much more slowly, peering under twigs in a thoroughgoing manner, usually singing as they go. Their larger heads and heavier bills will likewise distinguish them. With few exceptions the vireos are arboreal birds frequenting the shade trees of the city streets or small groves and wood lots, although they are not out of place even in the dense forests.

These modest birds are almost entirely insectivorous and to them, as much as to the warblers, is given the protection of the foliage. Leaf miners and leaf rollers, canker worms, elm leaf beetles, gipsy and brown-tail caterpillars and even the tent caterpillars are acceptable to them. In their seasons the berries of the elder and mulberry, wild cherries and even the hard blueberries of the Virginia creeper attract the vireos and make a welcome change in the usual dietary.

Vireos are great singers. They are singing when they come in the spring, and they continue to sing all summer, even after the exhausting molting period has caused other birds to cease. They sing under the hottest noonday sun when other birds are resting, and even on their way back to their winter homes they indulge in snatches of their cheerful, measured music. Unlike the warblers their songs are uniformly loud and musical, and though sometimes marred by a discordant chatter, have a finesse unusual in bird music. They are simple, however, usually repeating the same phrase over and over with regular rests between each syllable. So measured is the time that it is rather easy to distinguish the songs of the common species by the rate of delivery. The red-eyed vireo, for example, calls: "Look up" – 1,2,3 – "way-up" – 1,2,3 – "tree top" – 1,2,3 – etc. While the yellow-throated vireo, which has a somewhat harsher song, delivers it more slowly: "Cherries" – 1,2,3,4,5 – "sweet cherries" – 1,2,3,4,5 – "have some" – etc.

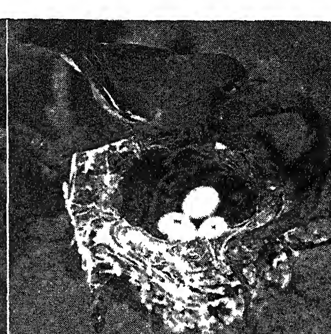
This method of singing has given them the name of "preacher birds", and, as Wilson Flagg has well said of the red-eyed vireo: "His style of preaching is not declamation. Though constantly talking, he takes the part of a deliberate orator, who explains his subject in a few words and then makes a pause for his hearers to reflect upon it." The songs of the warbling and the white-eyed vireos are exceptional, for the former indulges in a single long musical warble, similar to the song of the purple finch, except that it has a rising inflection at the end, while the latter, being an excellent mimic, often combines the songs of other birds with his own into an indescribable jumble of musical cadences.

The nests of vireos are basket-like structures hung in the forks of smaller branches. They are built of strips of grapevine bark and fibers such as the milkweed supplies, skilfully fastened together and bound in place by spider or tent caterpillar webs. One can be fairly certain of the species of the nest by its position in the tree or shrub. The white-eyed vireo, for example, always builds its nest in berry bushes or tangled thickets within a few feet of the ground. The red-eyed vireo nests on the lower branches of young saplings from five to ten feet from the ground. The warbling vireo builds high in a full-grown tree toward the tip of a branch, while the yellow-throated builds near the trunk or in one of the main branches, hanging its nest in the fork of a small shoot. The eggs of vireos are always white with a few specks of black about the larger end and are usually very thin-shelled.

The three commonest vireos are the warbling, red-eyed and yellow-throated species. The first two resemble each other closely, being greenish above and pure white below. The red-eyed, however, has a grayer crown and a black line through its eye. The yellow-throated vireo is easily distinguished from these two by its yellow throat and breast, resembling more some of the warblers. The blue-headed vireo and the less common Philadelphia vireo are more northern in their breeding range than the others and prefer woodlands for their homes. The blue-headed species is quite distinct from any of the others with its bluish-gray head and white eye ring, but the Philadelphia closely resembles the common red-eyed even in its song. Its underparts, however, are lightly suffused with greenish yellow and its song is somewhat weaker and higher pitched. The eastern and southern white-eyed vireo and the Bell's vireo of the Middle West are aberrant members of the family which frequent thickets and berry patches from which they scold at every passer-by in an amusingly impudent manner. The iris of the white-eyed vireo can be seen easily in the field, and gives the bird a quizzical expression.

Several other species of vireos are found in the South and the West and the number increases through Mexico and Central America, reaching their maximum abundance in the tropics, where the majority of the one hundred or more species are found. Vireos are confined to the New World and find their nearest relatives either with the waxwings or the shrikes.

FRIENDLY BLUE-HEADED VIREO INCUBATING



YELLOW-THROATED VIREO AT ITS NEST

FEARLESS RED-EYED VIREO INCUBATING

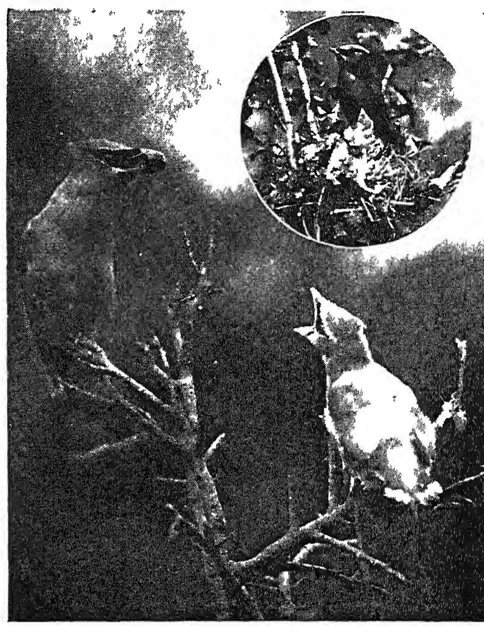
The Waxwings

The family of waxwings (*Bombycillidæ*) is one of the smallest families of birds, containing but three species. In spite of this, however, it has a wide distribution throughout the northern hemisphere, one species, the Bohemian waxwings, being found in North America, Europe and Asia. Waxwings are easily distinguished from other birds by their sleek, almost silky brownish plumage and their crested heads. The name is derived from the appearance of the inner feathers of the wing, which seem to be tipped with little drops of red sealing wax. Across the tip of the tail in the Bohemian and cedar waxwings is a band of yellow, but in the Japanese waxwing of eastern Asia the band is rosy red.

The Bohemian waxwing in this country is confined in summer to the Northwest, from Alaska to British Columbia, wandering erratically southward to the northern United States in winter, occasionally appearing as far east as New York and New England. It is a much larger and grayer species than the common cedar waxwing, having white bars in its wings and reddish under tail coverts instead of white.

The cedar waxwing, which is a fairly common bird throughout the United States and Canada, is better known in most places by the name of "cherry bird", because of its fondness for fruit. Until the fruit ripens in the summer the waxwings feed largely upon canker worms, elm leaf beetles and other orchard and shade tree pests, becoming expert fly catchers in the pursuit of insects. With the ripening of the June berry and the choke cherry, however, the waxwing varies its diet with a considerable quantity of fruit so that often about the sweet cherry trees, particularly where native fruit or mulberries are scarce, it, together with the robin, the oriole and the woodpeckers, becomes a veritable pest.

The waxwing continues this diet of fruit through the winter, wandering from the wild grapes to the mountain ash, Boston ivy and Virginia creeper berries, finally descending to the barberries in the spring when all other fruit is consumed. They travel in compact flocks until the nesting period, flying with a direct, even flight that can be recognized at a distance. Sometimes these flocks number hundreds of individuals but usually less than a dozen It is interesting to watch them feeding for they have gained for themselves the reputation of being the only birds or wild animals in which the rudiments of etiquette are developed. It is not an uncommon sight to see a small flock arrange themselves on a branch where only the one at the end can reach the fruit. He plucks it and very politely passes it to his neighbor and thus on down the line until the last bird is reached and he swallows it.



A CEDAR WAXWING ABOUT TO FEED ITS YOUNG
(Inset) Cedar waxwing, nest and young.

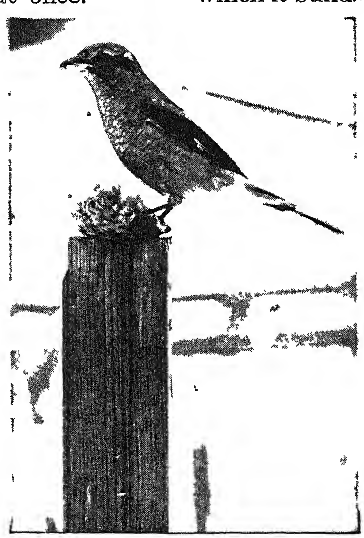
This can continue for some time before they scatter and commence feeding by themselves. The origin and meaning of this habit have not yet been ascertained but it certainly seems quite in keeping with their quiet and dignified bearing.

For some other unknown reason their nesting season is greatly delayed and although they are with us throughout the year, they wait until all other birds except the goldfinches have reared their broods before commencing to build. Some nests are started as late as September but

the majority are begun about the middle of July and a few as early as the middle of June. The nest is a rather bulky structure placed in a fruit or shade tree or often in a thorn bush from five to twenty feet from the ground and the bluish gray eggs are doubly spotted, some of the spots seeming to be put on beneath the surface of the shell.

Waxwings are faithful parents, one bird usually standing guard on some conspicuous tree top near the nest while the other incubates or broods the young. The food is brought to the young in the crops of the parent bird, their necks often appearing quite distorted when a half dozen or more cherries are brought back at once.

The best protection against the depredations of the waxwings and other fruit-loving birds is the planting of plenty of native fruit about the orchard to supply the food which they need, and an occasional frightening. Strips of paper or bright bits of glass or tin hung in the trees are sometimes effective, although it is usually necessary to frighten the birds occasionally by banging a tin pan or firing a blank cartridge. It is a short-sighted policy to shoot them, for they more than repay the farmer for the cherries by the insects which they destroy at other times of the year.



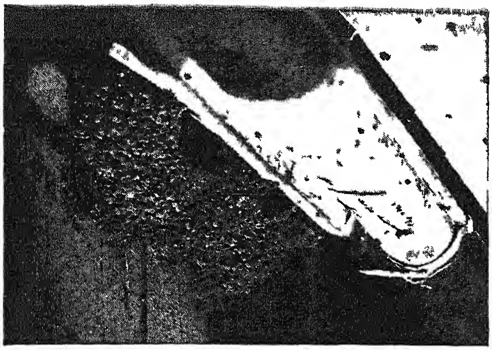
A NORTHERN SHRIKE ON A FEEDING POST

The Shrikes

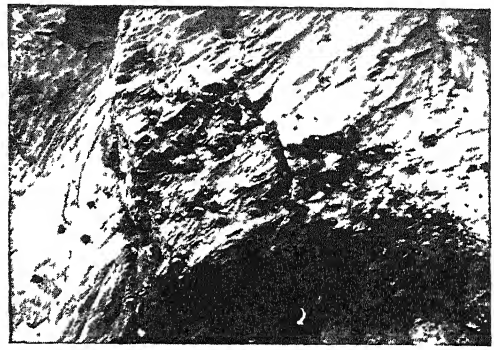
We are accustomed to think of the hawks, with their hooked bills and sharp talons, as bloodthirsty, but to discover a gray, robin-like bird with such propensities is a surprise. But when one has watched a butcher bird plunge into a thicket and come out with a sparrow in his bill, or has seen him hover above a bush in which small birds are chattering alarm, waiting the chance to corner one of them, or when one has found the shrike's prey impaled on a thorn or wedged into a fork in a branch, one cannot doubt his savage nature.

There are nearly eighty different kinds of shrikes in the world but only two of them, the northern and the loggerhead, are found in North America. These two birds resemble one another closely, being rather uniformly gray with black wings and tail and a black stripe through the eye They are about the size of robins, the loggerhead being somewhat smaller, and have the general appearance of a mockingbird The northern shrike nests in the far north and is known in the United States only during winter, but the loggerhead, in one or another of its sub-species, nests throughout the United States east of the Rockies, where it usually frequents thorn bushes in which it builds its nest, and upon the thorns of which it impales its food

The shrikes feed not only upon small birds, but also upon mice, grasshoppers and the larger insects. They usually select some prominent fence post or the top of a tree from which they can survey the country and may often be seen to fly directly to a spot several hundred yards away and catch a grasshopper as though they had eyes like telescopes. Their habit of impaling their prey has arisen not so much from their desire to store their food, as is commonly supposed, but because they are so constructed that they cannot hold their prey beneath their feet and still get sufficient leverage to tear it to pieces. By fastening it on a thorn or wedging it into a narrow fork, however, they can stand to one side of it and brace themselves as necessary. Their feet, moreover, are of the ordinary perching type and are never used to help them catch their victims, as with the hawks. Their bills are more strongly hooked than any of the other perching birds but not so strongly as the hawk's. That they are song birds is attested when the nesting season arrives, for both species develop songs of remarkable sweetness and variety



CLIFF SWALLOWS' NESTS UNDER EAVES OF BARN —AN ADAPTATION



NESTS OF CLIFF SWALLOWS ON A CLIFF —THE NATURAL NESTING SITE

The Swallows

Every land has its swallows. No summer landscape is complete without their graceful forms silhouetted against the sky or skimming over the water. Long of wing, light and sleek of body, they dart hither and thither with scarcely an effort, for their wings, their form of body, their very feathers have become modified to express flight, while their little-used feet have so degenerated as to be smaller than those of the tiny chickadees.

There are about one hundred different kinds of swallows, but only nine of these are found in North America north of Mexico, of which several are among our most familiar birds, building their nests about the barn, or in bird houses that are erected for them. They are all insectivorous birds, although one species, the tree swallow, is known to eat bayberries during its migrations, and spend only the summer months with us, retiring in winter to sunnier climes in South America.

Before starting for the south the swallows frequently assemble in enormous flocks and spend the night together, sometimes roosting in trees but more often in the marshes. Sometimes the telegraph wires along lake shores or near their roosting places are completely covered for hundreds of yards by the thousands of birds that have assembled. They begin assembling for their migration as early as the last of June, although occasional tree swallows may be seen in the northern United States as late as October. In the spring they arrive with great regularity, the purple martins often coming back to the house put up for them on the same day of April year after year.

TREE SWALLOW AND YOUNG

BARN SWALLOW HOVERING BEFORE ITS NEST IN THE BARN

A ROUGH-WINGED SWALLOW

In nesting, swallows are remarkably diverse. So we find the barn swallow building a cup-shaped nest of mud pellets glued to the rafters of the barn, and the eave swallow building a gourd-shaped structure of the same material beneath the eaves. Both formerly nested on the cliffs but have adapted their ways to suit the abodes of man. The tree swallows and the martins normally nest in holes in trees but have adapted themselves to nesting boxes, the former always nesting singly, the latter always in colonies. The rough-winged swallow utilizes the deserted burrow of a kingfisher or a cranny in the cliff, while the bank swallow lives in colonies and drills tunnels in the sand banks. Those species that nest in holes lay unspotted white eggs, but those that build nests lay eggs that are conspicuously marked with chocolate-brown.

The largest of the North American swallows is the purple martin, a bird about eight inches long, the males of which are uniformly steel-blue above and below, the females having gray breasts. The best known is perhaps the barn swallow, a smaller bird with a steel-blue back and orange-brown underparts. It is the only one of the American swallows that has a deeply forked tail like the European swallow.

The cliff swallow is somewhat similar to the barn swallow but has a square tail and on the rump a buffy patch conspicuous in flight The tree swallow of the East and the violet-green swallow of the West are alike in having pure white breasts, but the western bird has the back an irridescent green instead of blue Two swallows, the bank and rough-winged, have brown backs, and they are readily distinguished from one another by the conspicuous dark band that crosses the white breast of the bank swallow. The roughwing does not have this band but has its entire throat dark.


BANK SWALLOWS RETURNING TO THEIR NESTING PLACE


A BANK SWALLOW'S NEST AT THE END OF ITS BURROW

In some localities there seems to be a prejudice against the swallows, especially against those that nest under the eaves, and the nests are persistently knocked down. This is a great mistake, for they are among our most valuable birds, destroying thousands of destructive insects that are not ordinarily caught by other birds that spend less time in the air. There is a common belief that swallows carry bedbugs and harbor them in their nests to the detriment of the householder. The belief is founded on fact but the insects are of a different species from that which sometimes infest the abodes of man. The birds are therefore unfortunate rather than dangerous.

SOME OF THE INNER SENSES

Our Debt to Common Sensibility, the Organic Sense of Well-Being, the Muscular Sense and Equilibration

MISERIES OF INTERNAL ORIGIN

IN several of the chapters of this section we have discussed the so-called "five senses" which are the "gateways of knowledge" from the outer world to ourselves. So far as positive science goes at the present time, the list of such senses is exhausted in what we have discussed. But before we proceed to a set of senses which are markedly different in kind, since the stimuli which arouse them are not derived from the outer world at all, we are bound to make formal admission of the possibility that there may be other senses, common to all mankind, or perhaps only exhibited appreciably in a few exceptional persons, which acquaint us with external things in ways which sight, hearing, the cutaneous senses, smell and taste, do not cover at all. Questions are here raised to which we must endeavor to return as adequately as may be, in the uncertain and highly disputed condition of the available evidence. But here we note that our foregoing discussion of the senses which connect the brain with the outer world must not be regarded as excluding the possibility of such senses as might be called a "sixth sense" of direction, a "telepathic sense" by which its possessor might sense, feel or perceive, as if whispered, the thoughts of another person, a "magnetic sense", a sense of the presence of water under the surface, as in the described cases of certain water-finders, and yet other senses as to which the evidence and our present ideas are still more dubious.

At this present stage of our discussion, the existence of any of these senses or of any others, is neither asserted nor denied. The attitude of true science is that of skepticism, which literally means not making denial, as some suppose, but an inquiring *continuous looking about*, in the absence of final knowledge.

Meanwhile our duty is to proceed to the present end of our positive knowledge; and the first fact we discover is that, whatever may hereafter prove to be the truth regarding any supposed "sixth sense", not only are the five "senses" many more than five, but also there are quite a number of "sixth senses" to be found within the domain of the body, if we look for them properly. The most satisfactory way in which to define and distinguish these senses is to call them the inner senses, as distinguished from those outer senses, as they may be called, which we have already discussed. The feature which those outer senses have in common is that they are all concerned with the reception and interpretation of stimuli proceeding from without. But the domain of man, or the City of Mansoul, as Bunyan called it in his "Holy War", requires not only gateways of knowledge from without, but also means by which knowledge as to what happens within it can be brought to the notice of its central ruler; and no sooner do we look into this subject than we find that the life of man could not be successfully maintained for a single day were it not for those inner senses of which very few of us have ever heard or thought, yet which are indispensable to our lives, while even sight and hearing are not.

No doubt these inner senses are to be ranked on a humbler plane than sight and hearing, or even than the senses which have their seat in the skin, the tongue and the nose; but all those other senses are to be regarded as later, if higher, developments, the evolution and use of which are only rendered possible by the prior and continued existence of the inner senses, without which the body could never have been built at all, and could not be maintained for a day. The finest telescope in the world would be useless if the observatory from which it looked forth was only chaos within.

The organization of man's body only possible through the service of inner senses

We have to learn, then, that the internal organization of the body, by means of which the City of Mansoul is able to exist as a unity, despite its inconceivable complexity of structure and function, is only made possible by the service of the inner senses, some of which, though not all, must now be discussed. We cannot discuss them all, for the excellent reason that, as we just begin to realize, there is no end to them. When digestive juices pour into the stomach after food has entered it, something somewhere has *felt*, and has given orders accordingly; and that is merely one instance of an indefinite number, to which any of us can contribute units if we will.

But in the following pages we shall only discuss a few of the inner senses, which are more general and more constant in their action, and to which definite names have been given by the students of physiological psychology.

As we have already seen, sensibility — or irritability, as it used to be called — must be regarded as a universal attribute of protoplasm, or living matter; and our senses, even including vision and hearing, must be regarded as developments from a primitive sensibility which is possessed by every living part of every living creature, and therefore by, for instance, our own blood-cells and gland-cells and muscle-cells, and all the other cells that go to make up our bodies.

The general sense of being either "out of sorts" or "fit"

This sense cannot conveniently be called "common sense", but may best be called common sensibility; and we must realize that every living part of our bodies — every part except the enamel of the teeth, the extruded parts, of nails and hairs, and so on — is endowed with this primal sensibility, and that, in many cases, there are nerves which run to the central nervous system and convey this common sensibility, or something corresponding to it, up to the brain itself. When we are in ordinary health, we are very little aware of these vague, faint, yet "massive" sensations which reach the brain from practically all parts of the body at once. When we are feeling "out of sorts", or bored, or tired, or when we are just coming down with influenza, or when something is wrong with the body as a whole, this common sensibility is affected, and it is largely because this common sensibility is affected that "we" feel not quite ourselves, as we say.

On the other hand, the convalescent, or the town-dweller, breathing the air of the seaside or the mountain breezes, or even he whose physiological processes have been improved by a cheering letter, has largely to thank the altered condition of his common sensibility for his different impression of the world and life in general; it is really a different impression of, or from, his own body that he is receiving. It is very probable that the sense of "fatigue", and sense of freshness after sleep, mainly depend upon the quality of the "common sensibility" which pours in upon the brain from the whole body, in different fashion according to the condition of our cells at large when they are bathed in fluids that contain waste products, or are perfectly fresh and free from all poisons.

A very slightly higher development of common sensibility is what is called "organic sensation", or the "organic sensations", those which proceed, with a little more definiteness than common sensibility, from the various organs of the body, and notably from the alimentary canal and the heart.

Organic sensations that come from the principal internal organs of the body

These organic sensations are very often described as if they were only of importance when our attention is directed to them on account of their unusual character. Thus they play the chief rôle in the celebrated theory of the nature of the emotions which was popularized by the late Professor William James, and which we shall have to discuss fully at a later stage. But the wide discussion of that theory has led many psychologists and others to suppose that the organic sensations are only important when, for instance, we are conscious of the palpitation of the heart under the influence of, or in association with, the emotion which we call fear, or that which we miscall "love".

There is no doubt whatever that these organic sensations are very important at such times; and no one will question the great part which is played in our lives by such examples of organic sensations as hunger and thirst, nausea, colic, flushing, palpitation, impending suffocation, or breathlessness and so on. But the first and most important fact which we have to learn about common sensibility and the organic sensations, considered together, and especially in reference to the latter, is that these sensations furnish a sort of permanent background or substratum or pervading element in consciousness, an element which may be very vague and indistinguishable, and the very existence of which we may incline to deny until we have studied the subject, yet one which subtly plays a part of the first importance in our psychical life.

How the organic sense of well-being underlies all possibility of happiness

It is especially the study of the diseased mind that has contributed to our knowledge of this subject. Such studies have shown that our organic sensations, when they are as they should be, contribute to, or rather constitute, what may be called an "organic sense of well-being", which may sound a matter of small moment when first we hear of it, but which underlies all possibility of happiness. Everything outside us may be smiling and attractive, our pocket full of money, nothing irksome to do, no boredom to fear, but if our organic sense of well-being fails us, and is become an organic sense of ill-being, we are the most miserable of creatures. "Life's but a walking shadow", and happiness the mania of fools. This is the underlying psychological basis of melancholia, that great group which approaches the insane state in which the common and essential element is misery *of internal origin*.

What may be the cause of the perversion of the organic sensations in any particular case does not here concern us, but we are concerned to realize, once and for all, what part the perversion of this element of consciousness can play, and therefore what a part its right behavior plays, in our normal condition of happiness.

The misery of the person who has an organic sense of ill-being

Faced with a case of melancholia, or even with the organic depression or mere melancholy not positively insane, which we often meet around us, the tyro who only believes in the "five senses" is apt to think that the cure must be effected in terms of them — change of scene, cheerful surroundings, bright or soothing music, absence of noises, French cooking and so forth. He soon discovers that his patients may change the skies above them, but they have not left their misery at home. The unpleasant sensations which produce the patient's sadness do not arise from without, and cannot be removed, at any rate directly, by changing what is without. They therefore must arise from within. And while the tyro wastes his time on change of scene and company and so forth, the expert seeks to correct the morbid chemistry, the fatigue, the influenza poisoning or the physiological exhaustion which has perverted the organic sensations of the body, so that the unfortunate person's consciousness has a permanent and all-pervading element which is an organic sense of ill-being, and turns every external source of happiness or peace or nourishment into Dead Sea fruit.

Some day, when the facts of modern science are made popular enough to invade every home, it will be seen that these facts, which are so familiar to students of insanity, furnish the basis for a new-old philosophy of life. The old doctrine that the source of happiness is to be found within is seen with redoubled force when we realize that it is true not only in the purely spiritual or psychical sense, but also in the sense of our foregoing argument, which is at least as bodily as it is psychical.

The internal causation of unhappiness too little studied and understood

An infinitude of misdirected labor, of superfluous pity, of superfluous envy, of contempt at discontent, and of admiration at content in hard circumstances would require to be reconsidered if we were all acquainted with these simple facts of our bodily-mental organization. Notably would the spread of popular science — or popular knowledge, which means the same thing — in this respect enable us, all over the land, to avert incipient melancholia by understanding it and dealing with it in terms of its *internal* causation.

But at present the public knows little or nothing of this subject, while many of the medical profession know little more; and it is the experience of every expert in insanity that the warning signs of approaching melancholia are ignored, and the causes which produce it are maintained or increased, in an appalling number of cases, even by those who care most for the person in question, and would do anything to avert the calamity, if they knew. Meanwhile, with such preventable catastrophes on every hand, a writer can only try to state the facts as clearly and forcibly as possible, insisting not merely upon their scientific and philosophic interest, which is of the first order, considering that happiness is "our being's end and aim", which we all pursue, though it is within us or nowhere, but also upon the high importance of this discovery in relation to the prevention of a very common and probably increasing form of insanity which is responsible for a great number of tragedies, especially those which culminate in suicide.

Different types of optimism and of pessimism physiologically considered

This is one of the foremost subjects for discussion in any modern treatment of the subject of personal hygiene, and especially the hygiene of the mind, which far transcends in importance the hygiene of the body; and it can only properly be dealt with on the basis of the knowledge regarding organic sensations which recent work in physiological psychology has placed at our disposal.

"Feeling seedy" after dissipation, "run down" after a strain, looking on the world with a "jaundiced eye", even the very word "melancholy", which means "black bile" — all such states and expressions as these, together with their opposites, such as the successful lover's feeling of "walking on air", find their clue and content in what we learn of the "organic sense of well-being". Similarly, we begin to see that there are many types both of optimism and pessimism, and that there is a world of moral difference between the *emotional optimism* of, say, the revival convert, the *organic optimism* of the man who has just dined, and the *rational optimism* of the philosopher or the poet who believes that "there shall never be one lost good".

The movement-feeling which coördinates muscular action as one of the senses

Not far removed from common sensibility and the organic sensations is what psychologists call (movement-feeling) kinæsthesia, or kinæsthetic sensation, which is our feeling of the movements and of the consequent position of the various parts of the body, especially of the limbs. This sensation may well be expected to depend upon the muscles, which are the motor-organs, and it does so to such an extent that we used to speak of it as the "muscular sense" — the sense which has its seat, and indeed its end-organs, in the muscles. And the experiments made by disease have long ago demonstrated to neurologists that this "muscular sense" is indispensable for our successful management of our bodies, especially of our limbs.

But further inquiry has shown that it is more accurate to include the "muscular sense" in a wider term, for the very good reason that the muscles are not the sole end-organs of this sense, though their importance is first. We must include the tendons of the muscles, and the lining or synovial membrane, as it is called, of the joints. It is probable, also, that we should include a certain amount of sensibility in the skin, according as it is more or less stretched or relaxed or folded in the course of the movements which go on under it. The sum and meaning of the sensory impressions derived in these ways is that we know where we are and what we are doing. Otherwise such a feat as putting food into our mouth with the eyes closed would be quite impossible.

The spontaneous regulation of muscular action by which we write or sew

That part of kinæsthesia which is derived from the muscles and tendons serves to tell us of the degree of force with which the muscles in question are being put into action; and apart even from the fact that this helps us to know where the muscles and limbs actually are in space, it means also that we are able to regulate as we please the degree of force which we find desirable to use for our purpose. Without the muscular sense no one could play the piano, billiards, tennis, golf or even write or sew.

When we trace upwards to the brain those nerve-tracts in the spinal cord which serve the kinæsthetic sense, we find that they mostly go to that large and well-marked area of the cerebral cortex which we already know under the name of the psycho-motor area. It is evidently a matter of convenience and economy that the center for kinæsthesia, which is mainly composed of the muscular sense, should be intermingled with the center which controls and orders the movements of the muscles. But it is particularly to be noted that some strands of nerves which belong to kinæsthesia do *not* travel to the cortex or to the cerebrum at all. They branch off at lower levels and run instead to the cerebellum.

The apparatus in the ear that preserves our equilibration

The full meaning of this notable fact can only be revealed, however, when we study the last and, in many ways, the most remarkable of what we have called the inner senses, for this study will show us an admirable and subtle coordination between the kinæsthetic sense and another sense, quite distinct in situation and mechanism, which yet plays a complementary part to that of the kinæsthetic sense in the activities of the body. This last of all the senses of man, so far as we have positive knowledge of them, is known as the sense of equilibration, and it is the sense by which a man literally "keeps his head" in the turmoil of the world.

In our study of the organ of hearing, with the amazing structures which comprise what is called the inner ear, we encountered, within the hardest part of the temporal bone on each side of the head, a trio of semi-circular canals, filled with fluid, and placed at the vestibule, as it is called, of the inner ear itself This apparatus looks like an adjunct of the organ of hearing, and has been historically evolved with it But when we examine its functions we find that we are wrong in crediting it with the special function of locating the direction of sound Though its structure would seem exactly fitted for that purpose, in point of fact the vestibular apparatus, as it is often called, has nothing whatever to do with hearing.

An illustration of the association of nerves to promote community of function

True, it is at the vestibule, or, rather, it forms the vestibule, of the inner ear; true, also, its nervous supply joins that of the ear and forms part of the so-called auditory nerve But microscopic study of this nerve and its connections shows that, though we simply speak of the eighth or auditory pair of cranial nerves, we should be wiser to speak of two pairs, which might be called 8A and 8B. 8A is indeed auditory, as it runs to the cochlea and is therefore called the cochlear nerve. But the other, though bound up with the auditory nerve

for a part of its course, is totally distinct in origin, function and destination. It is usually called the vestibular part of the auditory nerve, but the more accurate name for it is simply vestibular nerve. This pair of nerves, one on each side of the brain, should undoubtedly be ranked as one of the pairs of cranial nerves, and might be called 8B. Its end-organ is the trio of semi-circular canals on each side of the head; and when we trace it inwards towards the brain we find that its fibers part from those of the auditory nerve proper, with which it has traveled part of the way for convenience, and pass to the cerebellum, instead of to the cerebrum, where the center of hearing is, of course, to be found. Lastly, we note that the fibers of this vestibular nerve actually become all but interwoven with the fibers already described, that come from the kinæsthetic path in the spinal cord, and that pass to the cerebellum instead of the cerebrum, like most of their fellows.

The semi-circular canals of the ear, and their relation to the kinæsthetic sense

Here, then, is a perfect anatomical demonstration of some community and complementariness of function between the kinæsthetic sense, which tells us where our limbs are, and the sense, whatever it be, of which the end-organs are the semi-circular canals. If the semi-circular canals from both sides be considered together, we see that, as the diagram readily shows, they form three pairs, arranged like the three dimensions of a cube, so that they exactly correspond to the "three dimensions of space". Whatever movements the head makes, or whatever movements it is made to make, as on board ship in bad weather, some pair or pairs of these canals will be affected. The fluid with which they are filled must tend to move. If a ship dips only, then only the vertical pair of canals (one on each side of the head) will be affected; if the ship rolls only, then only one pair of horizontal canals will be affected; but if she dips and rolls, and rises and falls, it will not be long before all six canals find stimuli affecting them, and the amateur sailor will very likely be seasick.

But seasickness does not mean that our semi-circular canals are superfluous, and are only there to annoy us. On the contrary, they serve for the head and the body, as a whole, just the functions which the kinæsthetic sense serves for the various parts of the body, and especially the limbs. It must be remembered that the head itself has only one movable joint — a pair of joints, of course — that of the lower jaw. The "muscular sense" has no end-organs, except the mere scalp, by which it could tell us where our heads are. Something more subtle is required, and these wonderful semi-circular canals are the solution of the problem. The evidence regarding their function is now conclusive.

The tragic confirmation by disease of the observations of physiologists

Professor Crum Brown, of Edinburgh, made a series of experiments upon himself and others by means of revolving tables upon which the subject stood, while they were rotated in alternate directions at graduated speed. He clearly showed how one's sensations in such circumstances exactly corresponded to the structure and arrangement of the six canals.

This is a striking instance of the value of having a *pair* of organs. It is decidedly advantageous to have a pair of eyes and a pair of ears, although a single eye or ear may become nearly as efficient. On the other hand, the doubleness of the vestibular apparatus is essential for its function, which is to register every movement and every possible combination and direction of movement of the head. The tragic experiments of disease precisely confirm the evidence of anatomy and the observations already mentioned. In disease of the vestibular apparatus, the characteristic symptom is an almost constant and uncontrollable vertigo; and it has been found that where only one or two, but not all, of the three canals on either side have been damaged or thrown out of action by nervous impairment, the patient's vertigo is limited to movements in the particular direction or directions of space which correspond to the canal or canals affected. This fact recalls our illustration from the case of seasickness.

The correspondence of the three canals to the three dimensions of space

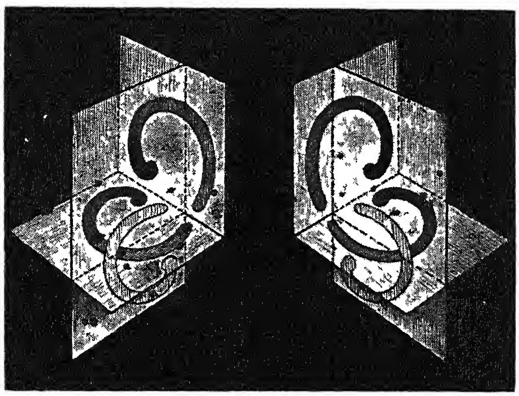
The details of structure of the vestibular apparatus are of comparatively small importance. The one essential fact as to the local machinery is that the three canals are arranged to correspond to the dimensions of space. For the rest, we need only note that the canals contain a number of special cells provided with hairs which project into the fluid which fills the interior of each canal. The column of fluid is so slender, owing to the tiny caliber of the canals, that we cannot suppose the fluid to be actually oscillated by movements of the head, as Professor Crum Brown originally suggested; but such movements will cause alterations of pressure in the fluid which must have just the same effect upon the hairs which are bathed in it as actual to-and-fro movement of the fluid as a whole would have. The reader who wishes to experiment upon himself in a less agonizing fashion than is involved in a bad sea-voyage need only exercise a little ingenuity for the purpose. The familiar fact that rotation in one direction makes one giddy, and that the giddiness can be most quickly annulled by corresponding rotation in the other direction, illustrates the exquisite fashion in which the three pairs of canals are adjusted, and in which they are fitted to appreciate every movement of the head, and to protest against whatever is unusual, and therefore possibly dangerous.

The inner senses the observant protectors of man

And if the reader is inclined to argue, as many students of the inner senses have done before him, that these senses are much exaggerated by scientific report, and that one really does not feel what one is alleged to feel, the answer is that these senses, which are protective rather than instructive — in even greater degree than touch, pain and smell — do not arouse the attention of consciousness except when there is anything wrong.

They leave us alone to live our higher lives so long as all is well, but they are on the lookout all the time, though our conscious selves do not trouble to perceive what they perceive. Though we largely owe our happiness to our organic sensations, we do not thank them when all is well, and we are indignant with them when anything goes wrong, and we feel giddy, "out of sorts" or "off color", though they are only doing their thankless duty.

Similarly, we may be inclined to deny the importance or the existence of our sense of equilibration, or the vestibular sense, as it is sometimes called, so long as all goes well. But the seasick tourist or airsick aviator, or novice in a ballroom, or victim of vestibular disease, is very well aware that the sensation of giddiness is exceedingly real, even though he cannot point to the sense-organ whence it arises, as he can point to his eye as the sense-organ of vision; and on consideration he will see



THE PLANES OF THE CANALS WHICH ACT AS THE BALANCE CHAMBERS OF MAN THE ERECT

that there must be a *sense of not-giddiness, too.* Here is a "sixth" — or should it be sixteenth? — sense which everyone possesses, and which no one can possibly do without; but the sense-organs, instead of being placed in relation to the outer world, like those of the outer senses, are buried deep in the hardest bone in the body, and have no channels of conduction from the surface, as has the inner ear, which lies so misleadingly close beside them.

Kinæsthetic and vestibular senses jointly used in acrobatics

No further comment need be made upon the anatomical fact that many fibers from the kinæsthetic tract of the spinal cord run to the cerebellum and join the fibers of the vestibular nerve there. We now see the meaning of this arrangement. Obviously, the kinæsthetic and vestibular senses work in harmony. The child that learns to walk, Blondin crossing Niagara on a tight-rope, the sure-footed and comfortable sailor, the trick cyclist — all these and a thousand more are instances of the education of these two senses. In dancing and in various forms of acrobatics they are still further developed, but they reach their highest possibilities in skating.

The classification of the arts in terms of the senses

If we are to arrange and classify "arts" in terms of the senses, a method which has its uses, then clearly the "art of skating" is the analogue, for the sense of equilibration, to the art of music for the sense of hearing, or the "gastronomic art" for the senses of taste and smell. But here, again, we must apply our criterion of the internal connections of the particular sense which we are cultivating; and the champion figure-skater or cook will be measured against the great musician or painter, according to the fact that the sense of equilibration leads to nothing more than equilibration and the consequent protection of the body, and has its center only in the cerebellum, while vision and hearing lead to instruction and revelation for the highest part of the psyche of man, which resides in the cortex of the cerebrum.

Relation between our conception of space and the number of the canals

One point remains, though indeed it is no point, but the root of a philosophical treatise, only parts of which have yet been written. We have included the sense of equilibration among the inner senses, and such it is; but evidently it gives us information about the external world, in that it tells us where we are in relation to the external world. Are we not, on reflection, bound to say that this sense of equilibration is really nothing less than our sense of space? Philosophy and mathematics argue as to the tri-dimensional character of space, and they can construct new geometries, super-Euclidean, on the assumption of a fourth dimension, which to length, breadth and depth adds an unthinkable "inwardness". Nor need they stop at four dimensions, for the geometry of space of any number of dimensions — *n*-dimensional space, as it is called — has been deeply explored of recent years. Observe that mathematics, including geometry, is preëminently the *exact* science, where proof and logic are rigid, and where casual or haphazard or superstitious thinking are instantly detected and condemned. But here we find mathematics constructing and proving to demonstration, and finding practically useful, a geometry which assumes that space has more than three dimensions. Obviously this leads the way to strange speculations, and opens the door to many possibilities, not least of all for the psychical science of the future. And here a question arises which has to be answered. The immediate relation between our conception of space and the number of the canals is indisputable, and requires explanation. It cannot simply be asserted as a coincidence; and philosophy must attempt to answer the question as to which is causally first — the number of the canals, giving rise to our tri-dimensional conception of space, or space actually tri-dimensional, and so causing the evolution of a trio of canals. The writer's own position is that he still inclines to the latter view, but with much less confidence than when he first studied the subject.

THE GENESIS OF ORE DEPOSITS

What can be learned from that part of the Earth's surface open to observation

AN INTERESTING PROBLEM IN GEOLOGY

MODERN civilization depends so directly upon metals and the consumption of them is increasing at such a rapid rate that the discovery of new deposits to replace those that are being depleted, and the economical utilization of the reserves now known, are problems that must receive the most careful consideration. These pressing needs have led to a scientific study of ore deposition in order to establish some principles to serve as guides in the search for mineral deposits and for their development. This has been to some extent successful, but the formation of an individual crystal of a mineral, and, to a much greater degree, that of a mass of minerals of sufficient size to be commercially workable, depends upon a nice balance in physical and chemical conditions, and these can only be inferred from the results they have produced. Hence much still remains to be investigated, and the following summrary of present opinion must be understood to be only an approximation to truth and necessarily requiring modification as further knowledge is obtained.

A comparatively small part of the earth's mass is available for direct study. The continents occupy less area than the oceans, much of their surface is itself covered by water, and many parts of it are so difficult of access that they have not yet received detailed examination. In addition, the depth which can be reached by observation is a very small part of the earth's diameter. Finally, there is the extreme variability in the character of the surface rocks which makes it difficult to obtain what may be termed a fair sample of the whole.

Attempts have been made, however, to reach some approximate value of the content of the common metals in the various rocks that occur in the outer part of the earth's mass, the "crust" of the earth. F. W. Clarke in the *Data of Geochemistry* gives the following average percentages of the metals in igneous rocks:

Iron	5.08
Manganese	0.125
Chromium	0 068
Nickel	0 031
Copper	0 010
Zinc	0 004
Lead	0.002

In the sedimentary rocks the elements listed above are not found in determinable quantities with the exception of iron and manganese. The former is as abundant in shales as it is in igneous rocks but is less abundant in sandstones and still less in limestone, and the latter occurs in small quantities in limestone as the mineral rhodocrosite. It is clear that even the rocks highest in the common useful metals contain a percentage of them far below the lowest content that could be mined profitably. Even though igneous rocks contain the metals in a much greater proportion than do sedimentary it still requires a very considerable concentration of them to form ore. Taking the averages given above it would require a concentration of ten to one to produce a workable deposit of iron and of two hundred to one to produce a copper ore. In other words, ore deposits are unusual phenomena, and the chief problem of economic geology is to determine the processes by which concentration may have occurred.

Igneous rocks may be assumed to be the original sources of the metals

From the lower percentage of the common metals in the sediments it seems reasonable to assume that igneous rocks are the original sources of the metals. This conclusion is corroborated by the fact that the sedimentary rocks are the product of the breaking down of igneous from which, therefore, the ore minerals must have come. Measurements of the weight of the earth show that the specific gravity of the whole must be several times that of the densest of the rocks known at the surface, and is so much higher than that of any minerals other than the metallic oxides or native metals that the assumption seems unavoidable that the depths of the earth consist of aggregates of much higher metallic content. It is possible that the core of the earth may be chiefly a nickel-iron alloy similar in composition to certain meteorites. Assuming this higher metal content of the deeper parts, it is conceivable that the igneous rocks which, in a molten condition, have invaded the outer part or "crust" should have carried out a metal content dependent upon the depth from which they have come. As, however, it is likely that the rocks on account of pressure can become liquid only at a comparatively shallow depth, the metal content is normally comparatively low.

The causes which result in the liquefaction of any part of the earth's mass are still largely matters of speculation, since, although these masses of molten material are formed at depths which are shallow with reference to the diameter of the earth, they lie far below the zone of observation. It has been suggested that heat may accumulate from atomic disintegration in depth and that any structural disturbance, such as that caused by the gradual contraction of the earth as a whole, may reduce the pressure at some favorable point to such an extent that the accumulated heat is sufficient to melt the rock. The same disturbance by which the relief of pressure is produced can be assumed to cause the movement of the molten material outward toward the surface.

How the formation of various types of rock is now explained

Many theories have been proposed to explain the formation of various types of rocks. It was long thought that as the molten mass, or magma, cooled down it divided into two parts which were not miscible and which separated as oil and water do after being mixed. This theory has met with some objections and the one now most widely accepted is that of fractional crystallization. As the mass of molten rock begins to lose heat those minerals which first reach the point of saturation at any given temperature will begin to separate out if there is any further cooling. In most magmas iron oxides and, in general, the minerals which are rich in iron and magnesium first reach the crystallization point. These minerals are heavier than the residual solution. Indeed most minerals are heavier than a liquid of the same composition (ice is the best known exception). The ferro-magnesium minerals sink toward the bottom of the magma chamber leaving the upper part filled with a residual poorer than before in iron and magnesium and hence relatively richer in silica, sodium, potassium, oxygen, hydrogen and many of the rarer elements. The crystallized minerals, sinking downward through the molten mass, in time reach a level where the temperature is higher than that at which they crystallized. It is then reasonable to suppose that they dissolve again and that the mass once more becomes completely liquid. The differentiation, however, will have been effected, the lower part of the magma being higher, and the upper part lower, in iron and magnesia than the original. Movements of the molten rock effected by any earth disturbances may result in transference of one or the other part into an entirely new position completely separated from its complementary portion.

The rocks high in iron and magnesia are referred to as basic rocks. Those which are rich in silica and in sodium and potassium are called acidic rocks. Certain types of ore are found only with basic, others are associated only with acidic rocks. Neither kind of rock in itself constitutes an ore

body, and it is only by concentration of the metallic elements of the magma, that ordinarily would be sparsely disseminated through the consolidated rock, that an aggregate of metal content sufficiently high to be an ore is formed.

Ore deposits formed by crystallization from basic rocks

Processes somewhat similar to that outlined above to account for the differentiation of the primary magma seem competent to produce from the basic differentiate concentrations of ore quality. As the magma high in iron and magnesium cools, certain minerals reach their saturation point and further decrease in temperature results in their crystallization In this way, iron and titanium oxides may separate and, sinking through the mass, may form crystals of the mineral ilmenite ($FeTiO_3$) Or iron and chromium, if the latter element be present, may result in the formation of masses of chromite. As the temperature falls still further the whole mass of rock may solidify and the product of the earlier crystallization then remains as workable deposits of ilmenite or of chromite. If, however, conditions be somewhat different the ilmenite or chromite crystals may redissolve as did the iron magnesium silicate minerals in the first differentiation. In that case a stratum of liquid material rich in iron or titanium or chromium may form at the bottom of the basic magma, and this material may find its way or be forced by earth movements into fissures or zones of weakness in the wall rocks of the magma chamber. In contact with cooler rocks this final differentiate crystallizes as a rock sufficiently high in ilmenite ($FeTiO_3$), or rutile (TiO_2), or chromite ($FeCr_2O_4$) to form an ore of titanium or chromium. Bodies formed in this way seem never to produce workable iron ores, since titanium is always present and produces ilmenite rather than magnetite (Fe_3O_4) and, under present metallurgical practice, ilmenite cannot be used as an ore of iron.

Concentrations of oxides of the metals have been referred to in the previous discussion, but it is also believed that some bodies of sulphides have had a similar history. The copper nickel deposits of Sudbury are believed by some geologists to have been formed by the settling out of the sulphides at the bottom of a great mass of basic rocks. Other geologists contend that the differentiation resulted in the formation of a mass of liquid sulphides which was then injected into its present position. Both theories present some difficulties but some such process has been widely accepted to explain these phenomenal bodies

In the primary differentiation of the basic and acid rocks the separation of the iron magnesium minerals from the sodium potassium minerals and excess silica is not complete. In each of the two parts into which the original magma has been assumed to be separated there are some of the constituents which form the greater part of the other component. Hence the part that on consolidation forms the acidic rocks contains also some iron and some magnesia, or, to put it generally, contains all of the elements in some proportion. The acidic portion of the magma normally includes the greater part of the boron, fluorine, oxygen and hydrogen, all of which have strong chemical affinity for most of the metallic elements. Hence there will be carried in solution in the acidic differentiate considerable quantities of iron, copper, zinc and other metals. There will no doubt be a considerable amount, also, of the iron magnesium silicates that were not completely separated from the acidic portion during the differentiation. Later crystallization of the acidic portion may therefore follow the same course as that of the basic portion, and iron minerals may crystallize and sink through the liquid mass to form concentrations in the lower parts. However, the iron oxides which separate from the acidic differentiate will be titanium free, and workable deposits of magnetite may result.

Ore deposits along the margins of igneous rock masses

The active chemical elements that are abundant in the acidic magmas commonly attack the surrounding rocks and replace part of them with the metals with which they are combined. By these reactions

the contact ore deposits are formed along the margins of the igneous rock masses. These are most common where granite intrudes limestone. The loss of CO_2 from the limestone produces space for the deposition of material from the high temperature solutions. The reactions are complex, and the relative importance of the igneous rock in the production of ore has been variously estimated by different geologists. It seems plain that the first effect is the recrystallization of any impurities the limestone may contain and, secondly, the elimination of CO_2 and its replacement by silica and various other oxides from the magma itself. Thus a zone of recrystallization continually moves outward, followed by a zone in which actual addition of material is made by the igneous rock. The replacement modifies and obliterates the products of the first stage of metamorphism. The final result is the production of zones between the igneous rocks and the limestone which consist of composite material, part of which has come from the invaded limestone and part from the intrusive. Iron, copper, lead, zinc, tin, tungsten and gold are produced from ores of this origin. The iron ores of this class are magnetitic, and contact metamorphic gold ores are commonly arsenical.

Ores formed by the residual solutions. The rôle of mineralizers

Important as individual occurrences of the types just described are, they produce only a comparatively small proportion of the total quantity of metals that man uses. A much greater number of ore bodies were formed during later stages of the consolidating magmas. As stated in the discussion of the differentiation of the original magma, the sodium potassium compounds are largely concentrated in the acidic portion. With them are a great many acid-forming elements such as fluorine, chlorine, boron, sulphur, tellurium, carbon dioxide, the hydroxyl radicle OH and other rarer elements. It was pointed out that many of these have strong chemical affinity for the common metals. For example, fluorine forms compounds with tin, copper and many others. In addition to those that are known, no doubt many compounds of these elements exist at the higher temperatures and pressures of the molten rock which are unstable at lower temperatures and pressures, and break up into the minerals that we know leaving no indication of the intermediate stage.

These active and commonly volatile elements and radicles are known as "mineralizers" since they are believed to play a very important part in the formation of many minerals. Under the pressures and temperatures which exist at depths of a mile or more below the surface of the earth it is likely that the volatile constituents combine with most metals, and so tend to prevent the complete settling out of the heavier elements and to retain a part of them in the acidic differentiate. Such conditions are necessarily unstable, and any changes of temperature or pressure may break down these temporary compounds and precipitate some of the dissolved elements. The presence of the mineralizers is necessary to hold the metals in solution and they will remain so only so long as the mineralizers are present.

An examination of the mineral constitution of any rock of the acidic class fails to show any large proportion of these volatile elements. In biotite granites the mica contains some of the hydroxyl radicle OH and certain granites contain some tourmaline, a mineral in which boron and fluorine are present. Apatite is commonly present in small quantities in many igneous rocks and it contains either chlorine or fluorine as an essential constituent. In no case, however, is there a quantity of any of these elements sufficiently large to have had any marked effect in producing an ore body of workable size. Nor would it be expected that such would be the case. From their nature, the volatile compounds are the last part of the magma to crystallize and hence, during the crystallization of all of the common rock-forming minerals, the volatile compounds move outward and escape from the cooling rock. When consolidation has been completed, only the small quantity represented in the minerals mentioned above will have been entrapped in the solid rock.

What becomes of the volatile elements that escape or are forced out

The question next arises as to what becomes of the volatile elements that have escaped or been forced out of the crystallizing rock. It is a common condition that there is a zone of pegmatite dykes surrounding masses of granite. The pegmatite tongues cut into the country rock or may occur in the margin of the igneous rock itself, thus showing that they are slightly later. Nevertheless they contain many of the minerals found in the igneous rock, are evidently part of the same magma, and are merely products of the later period of its crystallization. The pegmatites differ from the normal rock in that they contain many of the rarer elements and in much greater proportion. Tourmaline is abundant. Muscovite, which contains a considerable percentage of hydroxyl, is common. Topaz, in which both hydroxyl and fluorine occur, is found chiefly in pegmatites. Furthermore the texture of the pegmatites is much coarser and there is evidence of a long period of crystallization in which certain minerals have formed and then been replaced by others. Evidently conditions gradually change, so that minerals of one stage become unstable and are dissolved during later stages, and other minerals substituted in their place. Such events can be attributed to a gradual fall in temperature and an abundance of material and of solvents.

Several minerals which are not used as ores are obtained from pegmatite dykes. Well known examples of such are the lithium minerals of South Dakota, the rutile of Virginia and the zircon of Florida. In spite, however, of the variety of the minerals of the pegmatites few of the metallic minerals are found in commercial quantities in them. Molybdenite, the chief source of molybdenum, is mined from pegmatite deposits in Canada and the United States. Cassiterite, the chief ore of tin, is found commonly enough in pegmatites but efforts to mine such occurrences in South Dakota have not been successful. Some pegmatites are said to contain gold, but none of commercial value is known. It is true that parts of the gold quartz veins of the Porcupine district of Ontario, and of other similar occurrences, are of pegmatitic character, but examination shows that the gold occurs chiefly, if not altogether, in quartz or sulphides filling fractures in the pegmatitic quartz. It clearly belongs to a later period of mineral deposition. Many veins belong entirely to a period of crystallization later than that of the pegmatites. This is revealed by the fact that quartz in these lower temperature veins is different in character from that in the pegmatites, and it can be shown that the temperatures of formation of certain veins range not far above the boiling point of water since zeolites are common, and the temperature at which the minerals of that group form is probably not above 200° C. In these lower temperature veins water was abundantly present during the crystallization of the filling and many of the minerals are hydrated species.

Causes of the deposition of the minerals dissolved in the solution

The cause of the deposition of the minerals dissolved in the solutions that flow through a vein may be simply the fall in pressure as the distance from the intrusive increases, or in temperature as they are cooled in passing through colder rocks. In other places there seems evidence that it was caused by reactions between the wall rocks and the solutions. The solvent material—fluorine, boron or hydroxyl—is removed from the solution by the formation of secondary minerals in the wall rock and those constituents of the solution, the solubility of which depends upon the presence of some particular mineralizer, will evidently immediately precipitate if the mineralizer is removed. In other veins mixing of different solutions at intersections may result in precipitation of certain minerals by some form of chemical reaction. There is also the possibility that electrical currents or radioactivity may cause the crystallization of some minerals especially from the colloidal state. In all cases deposits belonging to this stage represent the last differentiate of that parent magma formed deep down in the earth. The tem-

perature of formation of minerals varies widely. Tin and tungsten minerals form at relatively high, lead and zinc at comparatively low temperatures. Between the two extremes there is a continuous series. Hence, normally, minerals have a zonal arrangement outward from the intrusive, those minerals which are characterized by a high temperature and pressure of formation lying near the intrusive and others being deposited in a regular succession outward from it.

If no other processes than those indicated were operative then it would seem as if all acidic, igneous intrusives should be surrounded by a zone of veins the metal content of which would depend upon the size of the intrusive. This would require an enormous volume of mineralizers when the size of some of the known deposits is considered. There are, however, factors which modify the location of the mineral concentrations produced by the excluded mineralizers.

Reasons for the localization of the vein deposited

The upper surface of any igneous mass is not smooth. As the mass works upward it probably makes room for itself by removal of blocks of the overlying rocks which sink into the molten material and are digested by it. Whatever the method by which it makes room for itself there are upward projecting domes or "cupolas". The volatile substances, as they are eliminated from the crystallizing magma, work upward through the viscous mass or through the fractures that are formed by changes of temperature in the invaded rocks or by pressure as the molten material advances. Fractures no doubt also develop in the marginal zone of the igneous rock itself, since a shell probably cools and cracks while the inner part is still quite liquid. In time, then, the mineralizers and the metallic load that they carry with them will be concentrated around the upper parts of the dome-shaped upward projections. Not merely the dissolved material from directly beneath any cupola will collect in it but all the matter from any part of the magma the roof of which slopes upward to the cupola. In this way the mobile extract from large masses of rock may be concentrated into a fairly small space and, when the solutions migrate out into the fractures surrounding the upper part of such a cupola, large masses of ore minerals may be precipitated according to the principles previously outlined.

Only igneous rocks that are intruded under a considerable cover of other rock commonly produce ores. Important ore bodies do not occur around the effusive rocks, possibly because pressure is necessary to take metals into solution and also because there is no structure to concentrate the ore solutions as the cupolas do in the deep seated rocks. At the time then of the formation of an ore deposit the depth below the then surface must have been of the order of thousands of feet, and ore can be exposed at the surface only through the gradual removal of the rocks which overlie it by the action of erosive agents such as wind and water. As the land surface gradually is cut down to the igneous rocks the satellitic ore bodies will first be exposed. With further down cutting the tops of the cupolas about which the ores are grouped appear. At a later stage when erosion has cut down to the main mass of the intrusive the ore bodies will have been completely removed (Fig. 1). Thus it is clear why small exposures of igneous rocks commonly have ore bodies clustered about them, whereas large areas of granite are characterized by barren contacts (Fig. 2).

Besides the deposits which are directly related to the igneous rocks there are others in which the concentration by which they are changed from disseminated occurrences into bodies of sufficiently high grade to be classed as ores, has been effected by agencies acting upon primary deposits. This secondary concentration may affect any of the primary types, or even rocks in which no primary concentration is present may be altered to such an extent that the small content of metallic minerals normally present may become aggregated into an ore body. Commonly, weathering is the process by which secondary concentration is produced. It may act in various ways. It may remove from the rock certain constitu-

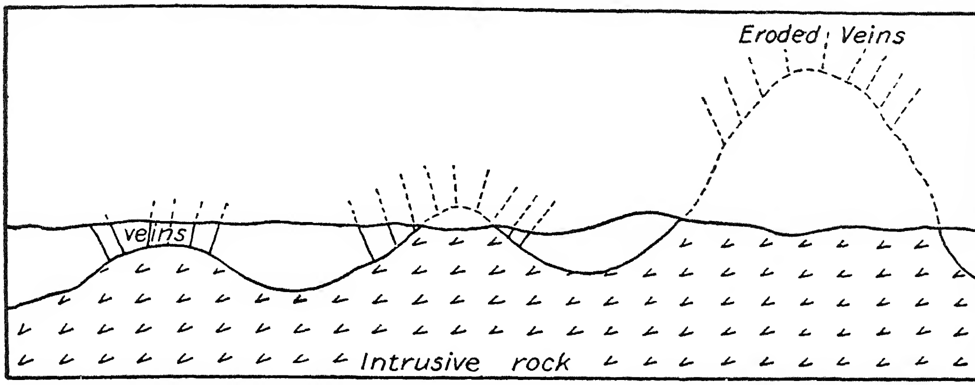


FIG. 1. Diagram to illustrate the clustering of veins around the upper part of cupolas. A is the land surface, which has cut below the ores of the cupola to the right

ents leaving a residual which has therefore a higher content of those which are difficultly soluble: heavy and insoluble minerals may be concentrated by the action of water or of wind into the sand or gravel deposits known as "placers"; soluble material may be transported by the run-off to other localities, and there deposited in veins or in beds of sufficient size and richness to constitute ores.

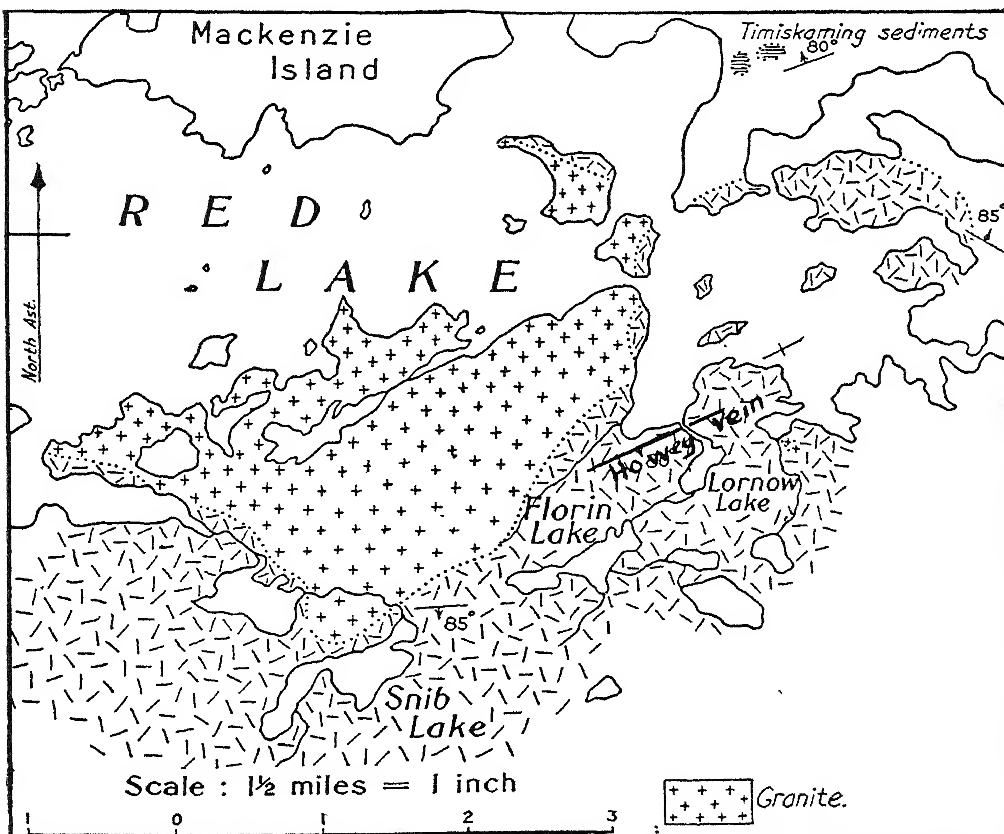


FIG. 2. Map showing relation of the vein to granite at the Howey gold mine, Northwestern Ontario. From Annual Report Ont. Dept. of Mines, Vol. 36, Part 3.

Residual ore deposits and their importance. The abundance of aluminum

Ore deposits formed by the removal of constituents so that the remainder may be high enough in some element to be ore are fairly common and are among the most important deposits of aluminum and of iron. Other residual ores of considerable importance are those of nickel and manganese. Aluminum is one of the abundant elements in the earth's crust. Calculations of the percentage of aluminum oxide in various types of rock give the following approximations:

Average for all igneous rocks . .	$Al_2O_3 = 15.34$
Average for shales	$Al_2O_3 = 15.40$
Average for sandstone	$Al_2O_3 = 4.77$
Average for limestones	$Al_2O_3 = 0.81$

Igneous rocks vary considerably in the percentage of alumina as the following table shows.

Granite . . .	Al_2O_3	12% – 15%
Syenite . . .	Al_2O_3	16 " – 19 "
Nepheline Syenite	Al_2O_3	18 " – 24 "
Diorite . . .	Al_2O_3	14 " – 17 "
Gabbro . . .	Al_2O_3	14 " – 18 "

To be an ore of alumina, material must contain 60 per cent Al_2O_3. To concentrate the alumina in nepheline syenite to ore grade would require that three tons of material be condensed to one ton without loss of Al_2O_3. Granite would require a concentration of over four tons to one. The rock-forming mineral which contains the largest percentage of alumina is feldspar and feldspars make up the greater part of most igneous rocks. Thus it forms approximately 60 per cent of granite, 65 to 70 per cent of diorite and 50 to 60 per cent of gabbro. On exposure to weather all minerals dissolve, but naturally in different degrees. In the granites the quartz which makes up 25 to 30 per cent of the whole is almost insoluble, but the oxygen, carbon dioxide and water in the atmosphere attack to a considerable extent all the other constituents. The feldspars are readily altered; the silica they contain is dissolved out as silicic acid, or as sodium or potassium silicate; calcium and magnesium dissolve as bicarbonates. Aluminum, however, forms first the hydrated aluminum silicate kaolin, or, if the weathering action continues long enough, the hydroxides bauxite or gibbsite. These are relatively insoluble so that very little aluminum is lost as the rock weathers. The loss of the soluble material decreases the total weight of the rock, and, as the aluminum present remains constant, the relative content of Al_2O_3 will increase. To produce an ore body, therefore, requires only complete weathering. Granite, since it contains so large a quantity of quartz, requires almost complete weathering of the other constituents, and the resulting bauxite is siliceous. Syenite, since it contains little or no quartz, produces a higher grade product. Gabbros and diorites, with their larger percentage of iron, form a product in which iron hydroxides are mixed with the aluminum hydroxides. Where the iron hydroxides form a large proportion the material is called "laterite" and is not then used as an ore of aluminum.

The effects of solubility and of weathering on mineral deposits

Iron in the ferrous state is fairly easily soluble, and the iron silicates, being mostly ferrous, lose a considerable proportion of their iron content by solution. Part of the iron, however, may be oxidized to ferric compounds which are difficultly soluble, and from them residual deposits of iron oxides are formed by reactions similar to those for bauxite. The alteration of a basic rock at Mayari, Cuba, has formed a blanket of iron oxides of workable grade and of considerable value, since they contain also some nickel which was present in the original rock. The Lake Superior iron ores are the product of the weathering of rocks, chiefly sediments high in iron, that were exposed at various periods of pre-Cambrian time. Localization of the solvent action has produced exceptional enrichments along troughs, or other structural basins in the rocks, but essentially the process is that outlined for the formation of bauxite.

When rocks are exposed to weather some minerals are partially or completely dissolved and the rock thus tends to disintegrate, although some of its constituents may be entirely unattacked. The mineral

grains set free are carried away by wind, or more commonly by water, and all streams carry a certain quantity of material in suspension. The size and amount of the suspended material depend upon the rate of flow of the stream and, hence, if a stream suffers any retardation of its rate of flow it will be able to carry less sediment and part of its load must be deposited. Such conditions arise at curves in a stream, so that bars are built out from the inner side of the curve as the current carries the water to the outer side. Where a stream debouches from mountains to a plain the gradient decreases, the rate of flow is less and, if the stream is carrying its maximum load, deposition of part of it occurs. Similarly, where a stream enters a lake or other body of quiet water, sediment is deposited as a delta.

The heavy constituents in the debris produced by the disintegration of the rock will be first deposited as a result of a decrease in velocity of the water. Variations in flow and changes of current will tend continuously to remove lighter material and to add to the deposit of heavy minerals, and, in favorable places, a considerable concentration of the latter may develop. even though the heavy minerals formed only an extremely small proportion of the original rock. Gold, platinum, cassiterite and scheelite are produced from deposits formed in this manner.

Ores deposited from surface water solutions sinking through crevices

Finally there is the group of ore deposits which are formed by precipitation from solutions formed during rock weathering. The oxidation, hydration and carbonation of certain elements in the surface rock produce soluble salts which are dissolved by the rain water. The solutions sink through the pores of the rock, or through crevices, and are added to the underground circulation, or they run off and are carried by streams to lakes or to the sea.

It is conceivable that the water that joins the underground circulation may under exceptional circumstances carry a considerable quantity of metallic salts in solution and that, with variations in conditions, minerals may be deposited in fractures or other openings in the rocks through which the solutions percolate, and in time an ore body may result. Veins of this kind will evidently be formed near the surface and the minerals will be those with low temperatures of formation. This origin has been assumed for the important lead zinc veins of Missouri and Wisconsin in the United States and for those of Gaspe in Quebec. Recently other views have been published by Tarr and Emmons for the Missouri veins, and the hypothesis upheld that they are the result of the action of solutions rising from deep-seated igneous rocks and, hence, belong to the group of primary deposits formed in the normal evolution of a cooling magma. Vanadium and uranium minerals occur in sandstones in several places in the southwestern United States and the character and association of these seem to indicate that there has undoubtedly been leaching, by ordinary surface waters, of the material from rocks of one horizon and the deposition of it in greater concentration in lower strata. The copper deposits of Mansfeld in Germany consist of copper sulphides disseminated in a black shale which contains abundant marine fossils. It seems most likely that they represent a basin of sedimentation in which was collected solutions from adjacent lands of desert character. The solutions carried considerable copper, probably precipitated by hydrogen sulphide formed as organisms decayed on the sea floor.

Some deposits of iron and manganese are without doubt formed by precipitation from solutions derived from weathering rock. Recent experiments have shown that carbonated water is the most effective solvent of iron occurring in the ferrous state in minerals and that organic acid formed from peat is next in effectiveness.[1] The drainage therefore, from areas where rocks that contain iron minerals are exposed to weathering, especially in the presence of peaty material, will contain some iron which it is believed is in the colloidal state associated with organic colloids.[2]

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[1] Economic Geology, E. S. Moore and J. E. Maynard (1929), Vol. 24, p. 276.
[2] Op. cit., pages 298–299.

Organic acid formed from peat, after carbonated water, most effective solvent

When solutions of this character collect in a lake the iron may be precipitated, as the iron hydroxide-limonite, by the action of bacteria. Siderite, the carbonate of iron, is the form deposited if the solutions are carbonated and air is excluded. Carbonate iron ores were formerly of considerable importance in England and will probably so be in the future in many countries, after high grade oxide bodies are depleted. Siderite may be weathered to form residual oxide deposits and that has been the history of many of the residual ores of iron.

Iron ore consisting of hematite with some siderite and some iron silicates is found as beds in regular succession in sedimentary series. One of the largest known bodies of iron ore, that at Wabana, Newfoundland, is of this kind. Many others of smaller size occur in rocks of Clinton age in the United States. The Wabana ores have an oolitic structure, that is they consist of tiny granules each of which has a concentric structure made up of alternate layers of silica and iron oxide, carbonate or silicate. They are evidently shallow-water deposits, since the beds below are ripple marked and show raindrop impressions. They contain the remains of marine organisms, and worm burrows are found penetrating the granules. Apparently at the time the ores were deposited there were shallow bays into which, at intervals, the detritus from adjacent tropical land areas was swept. This debris was rich in iron oxides and the water draining to the sea was high in iron solutions The sea water, with its content of sodium chloride, flocculated the colloidal iron oxides and silicates, and the iron, in the presence of the dehydrating salt solutions, may even have been deposited directly as hematite. The oolitic forms are evidence of the colloidal nature both of the iron compounds and of the interbanded silica. Manganese oxides are formed in a manner similar to the formation of iron oxides. Manganese minerals occurring in rocks of land areas exposed for long periods to weathering conditions, are dissolved and carried into lakes or shallow seas and there deposited. The largest manganese deposits that have been assigned to this type are those lying in the Georgian Republic, north of the Caucasus Mountains. They consist chiefly of oolitic oxides which form regular strata in beds of clay, marl and sandstone of Eocene age. The regularity of the structure makes the sedimentary origin quite evident, although there may have been some enrichment by decomposition of original manganese minerals subsequent to deposition.

Summary

A review of the origin of ore deposits shows that all metals are original constituents of igneous rocks in some proportior and that during the normal evolution of the magma there is a differentiation into basic and acidic rock types. From these, various ore deposits may be formed by concentration of the metallic minerals. The types may be classified as follows:

A. From the basic part of the magma by sinking of crystals, Titaniferous iron ores, Titanium ores, chromite, etc.
B. From the acidic part of the magma
  (a) By sinking of crystals
    Magnetite deposits
  (b) By contact action along the margins
    Magnetite deposits
    Copper deposits
    Possibly some gold deposits and various other deposits
  (c) By deposition from residual solutions high in mineralizers
    Cassiterite and tungsten deposits
    Gold deposits
    Copper deposits
    Zinc, lead and many other deposits
C. Secondary ore concentrations are produced by action of the weather on primary rocks or ores as follows:
  (a) Residual deposits
    Aluminum, iron, manganese and nickel ores
  (b) Deposits formed by mechanical concentrations
    Gold, platinum, tin and tungsten placers
  (c) Deposits formed by solutions derived from weathering of rocks or of primary mineral deposits
    Iron and manganese ores

The localization of the concentrations of the metallic minerals is largely the result of special structural conditions by which, by the action of one or more of these processes, a large quantity of mineral may be aggregated into small space.

THE CHEMIST AS CREATOR

How the Skill of Man in Combining Chemically Separated Elements Outrivals the Productions of Living Nature

PROBING THE MYSTERIES OF LIFE

THERE are certain chemical changes which the world has seen carried on since the earliest dawn of history. Iron, copper and other metals have been recovered from the earthy materials which contain them. Pottery and glass have been made from sand and some other common substances. With small beginnings such as these, men have slowly developed processes for making thousands of useful and valuable substances from less valuable materials. The alchemist was the first to undertake this work, then the druggist, and today the chemist. By 1840 the science of chemistry had many achievements to which it could well point with pride—processes for obtaining almost all of the metals from their ores had been worked out; all the necessary acids and alkalies could be cheaply made; pigments, soaps, explosives and a thousand other materials were produced on an industrial scale. In one particular line of attack, however, the chemist had to confess failure. He was unable to reproduce any of the products of living nature. The foods and textiles which make life possible — the odors, flavors and colors which make it more attractive — all these came as a result of that mysterious process which we call animal or vegetable growth. Though the chemist knew the elements from which they were made, he seemed unable to build up a single one of these "organic" products, although he made almost numberless attempts to do so. Finally, men of science generally agreed that none of the stuffs produced by the life-force could ever be manufactured profitably, if at all, by artificial means.

Yet, out of curiosity, chemists went on in their purely destructive work of trying to break up everything they could lay their hands on. They granted there was nothing to be gained by finding that starch and cotton were composed of the same ingredients, in the same proportions, or that sweet grape-sugar and the acid of sour milk were identical when they were broken into something that was of no use to anybody. The mysterious life-force, they admitted, was the only power that would turn a mixture of the elements of charcoal and water first into a foodstuff and then into a dress material. Then why go on with your work? said practical men. Well, replied the chemists, it is very interesting to find what living matter is made of; and even though we never get to the bottom of the problem, yet we may manage to add a little to the sum of human knowledge.

These chemists who destroyed the stuff of living things, by all sorts of ingenious means, were not encouraged in our practical country. There was apparently nothing in common between them and the really useful men of science, who kept to the study of metals and minerals and other things that could be made into new mixtures without the help of the mysterious life-force. Business men appreciated the achievement of chemists who worked out the manufacture of a saleable article from some waste product. But the few and far-scattered men of science who vainly tried to pry into the creation of living matter were not appointed to professorships of importance in this country or abroad.

How the synthetic chemist holds in his hands the destinies of the human race

Now, however, the disciples of these few men hold in their hands the destinies of the human race. Without them, the people on our overcrowded planet would soon be compelled either to restrict the number of children to which they give birth, or to submit to a constant and increasing diminution in the supply of food. Happily, however, the modern chemist has won a larger power of creation than that possessed by the so-called "life-force" Out of his long and apparently useless attempts to break down starch into the same elements as cotton, there has slowly been developed the opposite power of combining the elements of lifeless matter into substances exactly similar to those produced by plants and animals The work of analysis has shown that the substances of our bodies, the fragrance of a rose, the stuff of life in a microbe, the fruit of an apple-tree, and all the bewildering variety of living products are chiefly based on combinations of four elements. The carbon that we find in coal is the foundation; the nitrogen of the air is also important, and so are the oxygen and hydrogen that are combined in water.

From these four elements, with admixtures of certain minerals, the substances of the living world are now known to be composed. There is no longer any difference between the chemistry of living stuffs and the chemistry of lifeless matter. Man has got control over the four elements with which the spirit of life clothes itself. He can do more in his laboratory than the life-force can in the plant and the animal.

How mind has been breaking down matter to find its elements

For instance, fifty years ago the organic compounds derived from animal and vegetable sources, such as sugar, starch, oils, fat, gums and resins, could be counted only by hundreds. Today, however, their number exceeds one hundred thousand; and most of them are created in the laboratory of the chemist and in the chemical works which he has brought into existence.

Synthetical chemistry, as this extraordinary power of outrivaling natural forces is called, is still built on destructive work. Generations of chemists sometimes labor for a hundred years in pulling a well-known substance to pieces, in order to study the atomic structure of the elements composing it A few years ago they succeeded in even breaking up the atom into a thousand parts, which they weighed and measured. But, having done this and reduced the entire matter of the universe into something quite impalpable, they have gone on to weld the broken atoms together into a multitude of strange and new combinations.

The dreams of what might be done if mind only took command

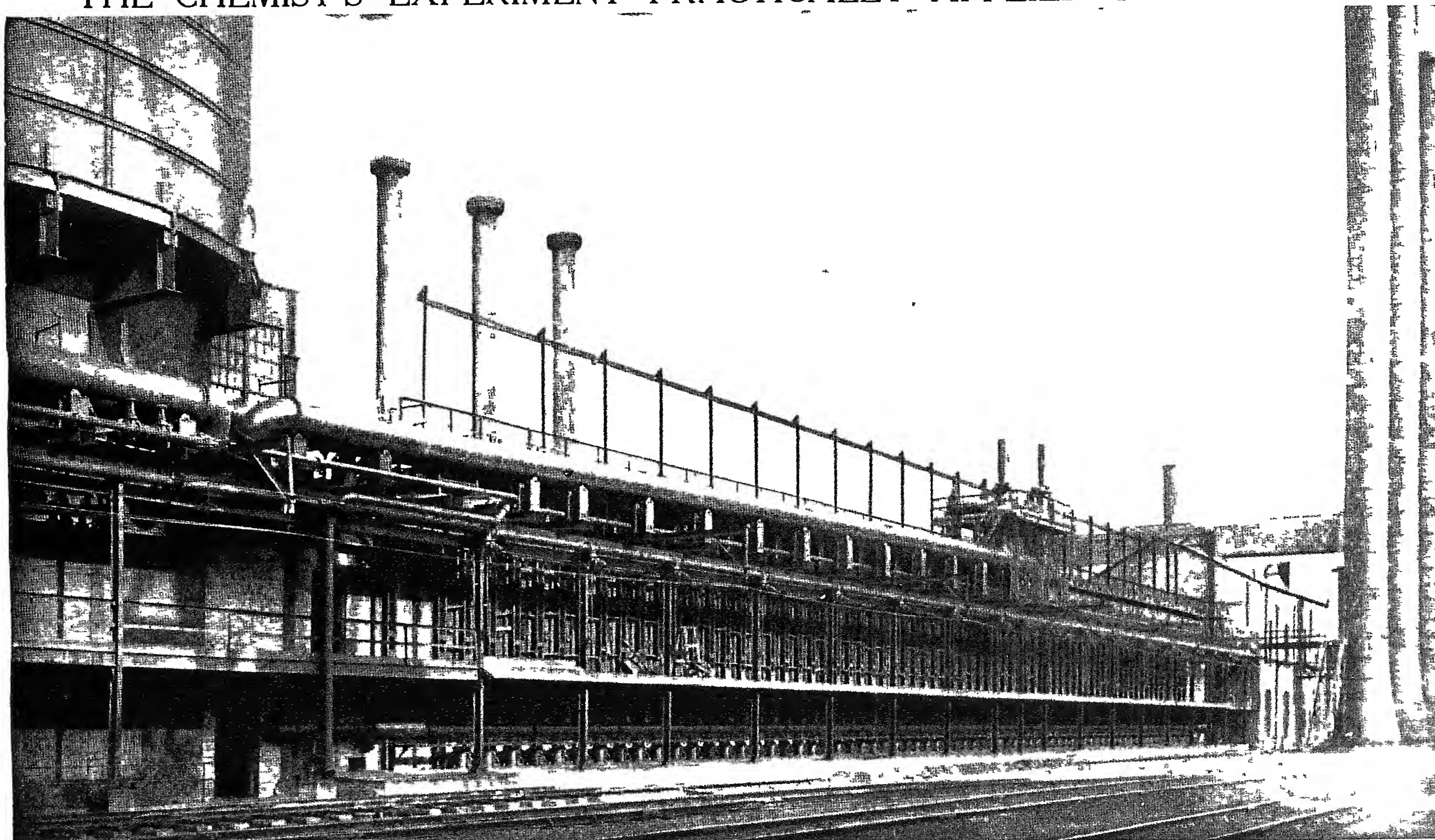
Only where natural conditions were very favorable could the mind of man display a little of its wonderful faculties. Merely in dreams did it feel itself the king of the material world; in its waking hours it found itself still the slave of matter. It was brutalized and starved, tortured and fettered, by the stuff that it wished to weave into an earthly garment of its own making.

Ah, those proud dreams that the spirit of man has dreamed in its hours of utter weakness! From the savage of the Stone Age, with his fairy tales of some magic power over nature, to the alchemist of the Middle Ages, with his fancies of a philosopher's stone that would change lead into gold, and of a medicine of immortality that would prolong his life for hundreds of years, the baffled and yet creative human soul has consoled itself in the hour of its defeat with wild and romantic prophecies of its future triumphs.

The coming true of some of the wildest dreams of man

And now, strange and impossible as it seemed only one hundred years ago, these prophecies are at last seen to have an element of truth in them. Men, if they like to take the trouble, can now turn pieces of charcoal into real diamonds, and manufacture rubies and sapphires out of two cents' worth of emery. They can also

THE CHEMIST'S EXPERIMENT PRACTICALLY APPLIED TO INDUSTRY



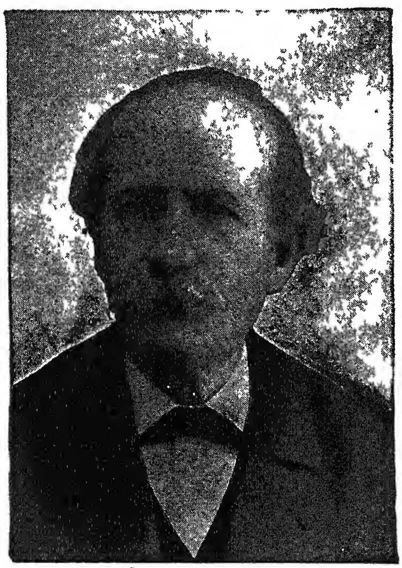
Courtesy H Koppers Company

MODERN BY-PRODUCT COKE OVENS

Eight batteries of seventy ovens each at the plant of the Illinois Steel Co , Gary, Indiana

change, if they will, several elements into others, and they can fly through the air quicker than the swiftest bird. They have a magic voice, by means of which they can talk with a man three thousand miles away, and even now they are easily able to see through the walls of a thousand houses by means of a magic eye, to which an electric wire and a set of mirrors are attached.

A great many of these victories over inert matter are the work of the modern chemist, armed with retorts and tubes, stills and electrical appliances. It is the chemist who has recently given man rays



PIERRE EUGÈNE MARCELLIN BERTHELOT

by means of which he can see through his own flesh, and drugs that enable him to conquer the most terrible of diseases.

Artificial building-stones in great varieties, artificial silks and other fabrics, artificial foods, perfumes and dyes, furniture made of mud and chalk, food for plants obtained by electricity from the air, are a few of the creations of modern chemistry.

There can be no doubt whatever that the modern synthetic chemist has entirely revolutionized industry and agriculture. Not so very long ago one of the prosperous industries in France and other European countries was the cultivation of the madder plant, which yields the important dye alizarin, used to dye cotton Turkey red. Cloth dyed with it has been found on Egyptian mummies, so its use dates back to a remote age. In 1868, however, Graebe and Liebermann made artificial alizarin from anthracene, a coal-tar product. As this process was developed and cheapened, it slowly ruined the madder industry, and it is many years since the plant has been cultivated at all. More recently, by a series of researches lasting about twenty years, German chemists have swiftly and completely ruined the indigo industries of India, which in 1895 were worth $17,000,000 a year. Practically all indigo now used in various countries of the world is manufactured from coal-tar.

At first, synthetic indigo was only an academic victory of the modern chemist. He took natural indigo to pieces and found the elements of which it was composed, and the way in which these elements were grouped. He saw that the grouping was somewhat similar to that in naphthalene, a very cheap coal-tar product from which moth balls are made. He therefore tried to build up indigo from naphthalene by a long series of experiments, which finally succeeded after years of effort. But the process was too slow and costly to interfere seriously with the natural production in India. There are many cases of this sort in modern chemistry. The man of science primarily seeks for the actual power of reproducing in his laboratory the living substance that he has broken up into its ultimate elements. It is the joyful exercise of his strange creative powers that leads him to give up the great part of his life to attacking a single problem. When he has solved it, and made five cents' worth of artificial indigo at a cost of thousands of dollars and many years' work, he has done with the matter. He leaves the use and the profit of his discovery to the manufacturing chemist, and turns himself to some new point of attack in the chemistry of living things.

It was a pure accident that changed the discovery of synthetic indigo into a vast German industry that ruined the indigo-growers of India. In a certain part of the artificial process, it is necessary to change

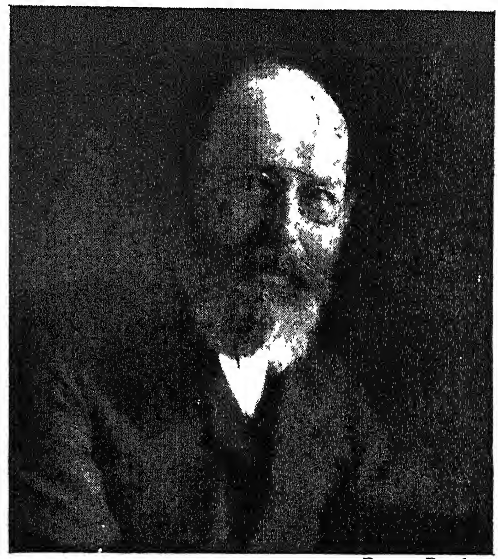
naphthalene into phthalic acid. This can be done by the action of hot sulphuric acid, but the method is very slow. All kinds of experiments were made with a view to quickening the action, and in one of the tests the thermometer used in registering the temperature was accidentally broken, and the mercury fell into the hot mixture. The action of the sulphuric acid was strangely quickened by the presence of the mercury, and this curious accident suddenly brought about the desired improvement of the process. Possibly, if the bulb of the thermometer had not broken, the rich and happy indigo-growers of India would be still smiling at the costly synthetic product elaborated by a German chemist.

There is another chemist, Komppa, who seriously interfered with the plans of the Japanese government. In the war with China, Japan had acquired the island of Formosa, the only rich source of camphor left in the world. There was a great demand for this substance in all civilized countries for making celluloid photographic films and various high explosives; and, instead of the supply growing with the demand, it woefully decreased every year. All the great camphor forests of Borneo and Sumatra had been destroyed, and even in Formosa the industry was gradually dying out. For camphor could only be made by cutting down the big trees, at least fifty years old, chopping up the wood and steaming the chips in furnaces, and the production was running short for lack of such trees.

On the other hand, there were large tracts of camphor forests still left in the savage interior of the island; and as Japan was burdened with an enormous debt after the war with Russia, her government resolved to use its monopoly in camphor in lightening the national debt. A series of military expeditions quelled the Formosan savages, and men of science and electrical engineers followed the troops, and surrounded the valuable forests with live electric wires. Very often the process of distillation was carried on with armed sentries watching over the laborers to defend them from the raiding savages.

Then, as the camphor-trees were practically exhausted in the settled districts, the Japanese government began a scheme of reforestation on a huge scale. In 1906, 346,000 trees were planted; in 1907. 1,300,000; in 1908, 4,830,000; and in 1909, 5,060,184. Thus, by intelligent foresight and keen business talent, the Japanese apparently succeeded in creating a most valuable monopoly in a natural product which was absolutely necessary in various important industries in Europe and America.

In the meantime the Japanese government began to sell their camphor on a



Brown Brothers

PROFESSOR EMIL FISCHER

rising scale. In about four years the price was increased by more than one and a half times, which enabled the government further to stimulate the industry by paying the producers higher wages. Moreover, the general demand was not lessened by the sudden rise in the market price. So many new industries urgently needed the stuff that the supply was still inadequate.

It seemed as though the Japanese government had obtained one of the most prosperous monopolies in the world. But, by the irony of fate, just when the Japanese in 1903 began to raise the price of natural camphor, Komppa completed the work on which chemists had been engaged

for more than a century. He succeeded in synthesizing camphor in his laboratory. Industrial chemists then took up the matter; by 1905 they were able to manufacture camphor at a price that prevented the Japanese from making the natural product too expensive. At present a camphor that is practically identical with natural camphor in its properties can be synthesized from oil of turpentine.

The development of synthetic rubber, a triumph of creative chemistry

One of chemistry's greatest triumphs has been the development of synthetic rubber. The history of this product goes back to the sixties of the last century. It was then that an Englishman, Greville Williams, produced a substance called isoprene by heating natural rubber in such a way that air could not get at it. From isoprene Williams then made a "pure white, spongy, elastic material" that somewhat resembled natural rubber. However, it had no practical use.

In 1910 German chemists succeeded in making isoprene out of coal tar and they turned it into a solid rubber-like material by heating it in closed tubes. Soon afterward they began making a synthetic rubber, called methyl rubber, out of methyl isoprene, isoprene's first cousin. For a year or two the Germans marketed this substance with fair success. Then a drop in the price of natural rubber made the manufacture of methyl rubber unprofitable.

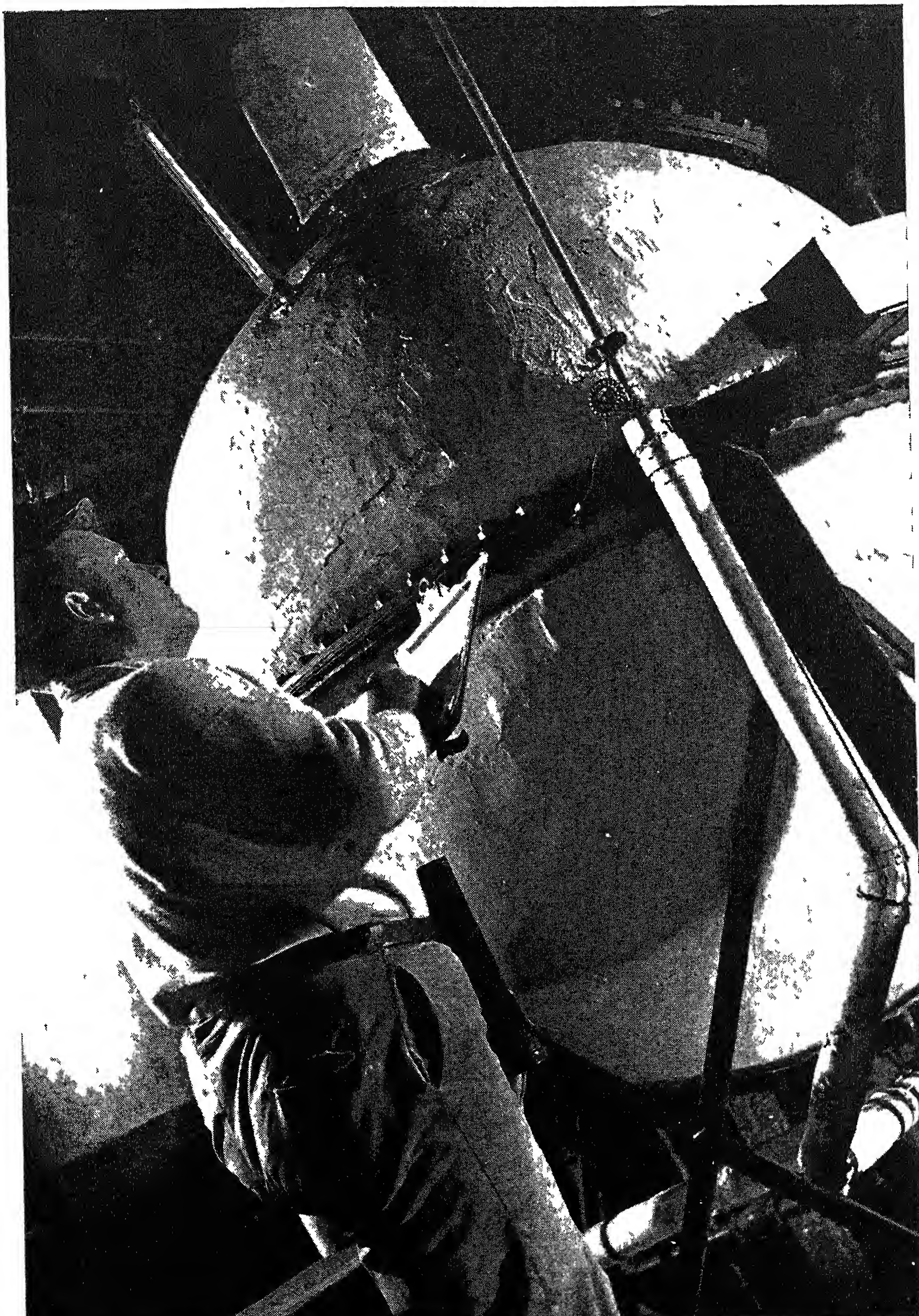
In the course of World War I (1914–1918) the Allied blockade cut off most of Germany's natural-rubber supply. In this serious emergency the Germans again turned to methyl rubber. They used it for the tires of some of their trucks and gun carriages and also for the storage batteries of their submarines. But methyl rubber proved to be such poor stuff that the Germans stopped manufacturing it as soon as the war came to an end.

In 1925 American and German chemists tackled in earnest the problem of making a synthetic rubber that would challenge comparison with the natural product. Their efforts bore fruit. For one thing, they understood by now much more about the chemical composition of natural rubber. They understood that it is a polymer; that is, that it consists of a great number of molecules linked together to form a chain. Research workers succeeded in linking together the molecules of other materials so as to form polymers that had many of the properties of natural rubber. By the beginning of World War II (1939–1945) chemists had perfected not only one but five different kinds of successful synthetic rubber: neoprene, Thiokol, Buna N, Buna S and butyl. These products could be manufactured out of such readily available materials as petroleum, coal, limestone, grain, salt and water.

When the Japanese captured Malaya and the Netherlands East Indies in the year 1942, the United States was cut off from the rubber formerly supplied by these regions. The natural rubber that Africa and South America supplied could not meet the need. Fortunately effective synthetic rubber was now available. America expanded its manufacture of synthetic rubber to such an extent that the rubber crisis was at an end months before the end of the war. After the war chemists continued to improve synthetic rubber. Today it is no longer a mere substitute, to be used when the original material is not available. It is as good as natural rubber in many ways, and in some ways it is better.

Important stages in the development of synthetic chemistry

Let us now sketch briefly some of the important stages in the development of synthetic chemistry. It was in the year 1828 that the German chemist Friedrich Woehler succeeded in synthesizing the organic compound urea and thus made synthetic chemistry a recognized possibility. For years research in this field was undertaken and carried out in a spirit of scientific investigation, without any expectation of hard cash returns. The earliest syntheses usually cost at least ten times as much as the final product was worth. The only reward of these pioneers was the mental satisfaction and the honor that came from each successful attempt to rival nature, even at a prohibitive cost.



Du Pont

A miracle of synthetic chemistry: this vacuum still is one of a battery that from coal tar, a crude chemical substance, derives a delicate perfume—*aubépine,* the characteristic odor of the hawthorn.

Early stages in the development of creative chemistry

By 1850, however, there were a few who had begun to dream of commercial possibilities in this line of work. Investigation and research carried out with the definite object of making money is a little less romantic than heroic attempts to win nature's secrets for the sake of knowledge alone, but they have an appeal to many scientists beyond that of mere financial gain, because they usually benefit large numbers of people. One such group of dreamers was working in England under Hoffman in an attempt to synthesize quinine and other valuable drugs. One day in 1857 Sir William Perkin, then a lad of 18, produced a beautiful colored solution in the course of his experiments. As his father had been a dyer by trade the possibility of using it as a dye occurred to him. Finding that it worked admirably, he started up the manufacture of that and other dyes, although Hoffman protested strongly at this "degradation" of his scientific abilities.

Perkin's success in 1857 excited a whirlwind of competitive enthusiasm. Everybody who could devise a new oxidizing agent at once tried it on some coal-tar preparation, and obtained a new dyestuff, and forthwith patented his process. Chief among the new dyes was magenta, which became the storm-center of a struggle between rival chemists. In France a great monopoly arose, and then men behind it tried to bring England and Germany under their heel. This excited a feverish activity on the part of English and German chemists. They had to find the secret composition of the new dye before they could attempt to reconstruct it by a better method. In 1878 the secret was discovered mainly by the labors of two great German chemists. It was not, however, till 1893 that Jennings assisted Professor Emil Fischer in filling all the experimental gaps in the science of the new dyes.

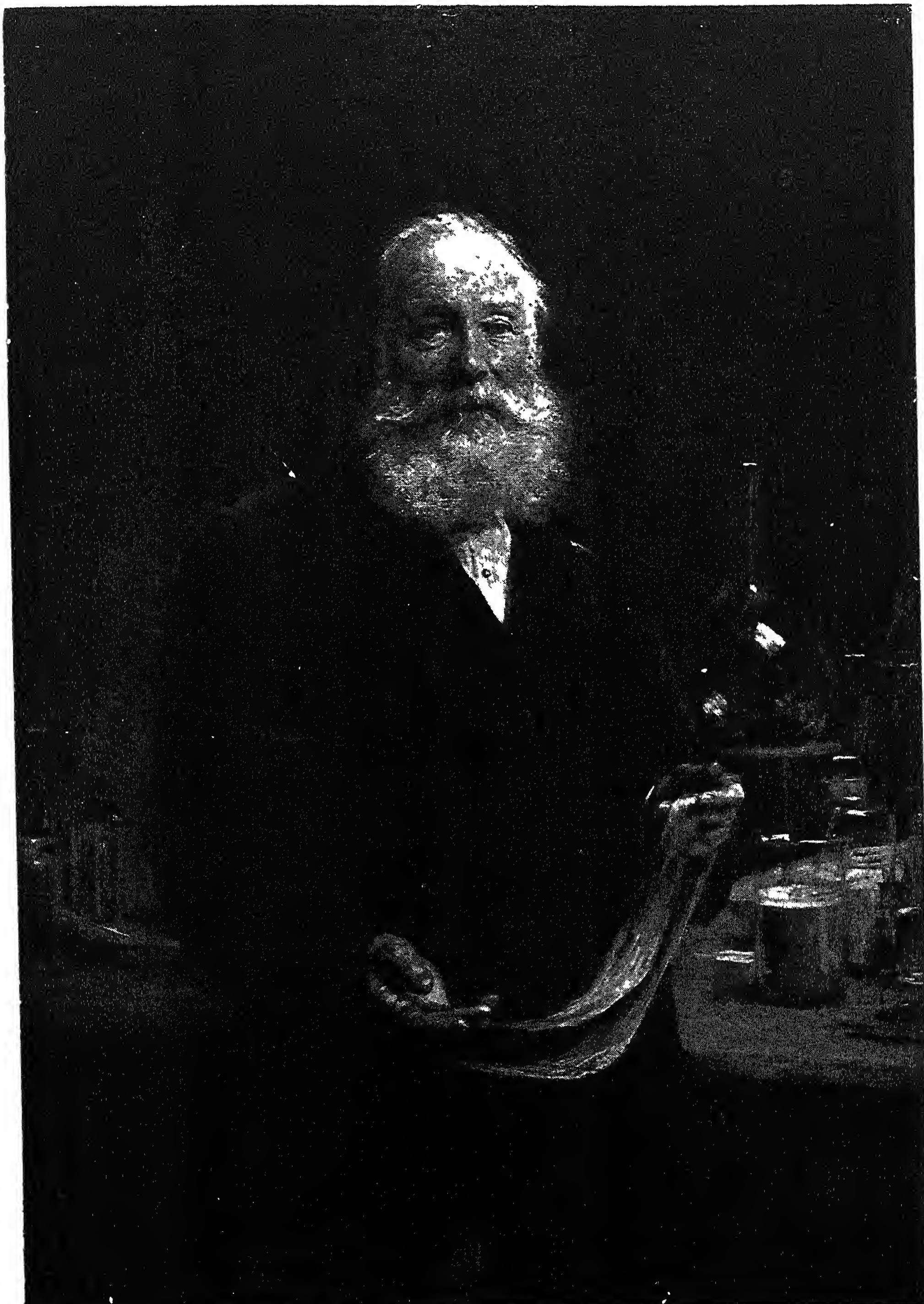
In the meantime, a progressive company of German manufacturers had backed the chemists who were fighting the French monopoly, and they were rewarded by a finer monopoly than that which they had helped to destroy. Instead of the old coal-tar dyes, that were few in number, impurely distilled, and very apt to fade, the German company obtained an extraordinary, long series of pure and fast colors of exquisite gradations.

It must not be supposed that these results came without hard work, or that they were accidents such as that which led to the discovery of the first aniline dyes. On the contrary, they came as the result of deliberate, long-continued effort to learn the constitution and chemical nature of and all other facts relating to some compound, and then to synthesize it from cheaper materials. The synthesis of indigo, which we have already mentioned, is a case in point. One company in Germany spent nearly twenty years of intense practical effort, spending many thousands of dollars, and employing almost continuously dozens of highly trained chemists. When they did attain success, they knew so much about the constitution and properties of indigo and similar substances that they were soon able to put on the market an extraordinary set of fast and brilliant red, green, and yellow dyes which are very similar indeed to indigo in their chemical structure.

The wonders of the modern coal-tar dye industry

Today there are about 2000 distinct coal-tar dyestuffs, ranging through all colors of the rainbow, and complying with every demand of stability, taste and fashion — all of which were derived by the synthetic chemist from what was once only a foul, ill-smelling waste product, everywhere regarded as an unmitigated nuisance. They have not merely matched and duplicated nature's colors, but far surpassed them in uniformity, brilliancy and permanence. Surprising indeed is the fact that from one ton of common soft coal there may be derived the essential materials to dye the following lengths of flannel three-quarters of a yard wide: 2 miles yellow, $1\frac{1}{2}$ miles scarlet, $\frac{3}{4}$ mile violet, 1400 feet magenta, 700 feet Turkey red, 370 feet orange!

THE ALCHEMIST OF COLORS FROM COAL-TAR



Sir W. H. Perkin discovered aniline dyes in coal when he was a lad of eighteen, mauve being the first color he secured. Enormous industries are built on the scientific foundations he laid down. This portrait is reproduced by courtesy of the artist, A. S. Cope, R.A.

Coal-tar dyestuffs used for dyeing many other things besides textile fabrics

Nor are these dyes used only for dyeing textile fabrics like wool, silk and cotton, but for many other materials such as paper, feathers, straw, bones and ivory. Indeed, whole pieces of furniture are often dyed by dipping them bodily into huge dye vats. They go in as ordinary pine wood, and come out "real mahogany," "walnut," "rosewood" or some other fancy wood. On the other hand dyes are used in extremely minute work, such as staining biological specimens for the microscope. Different dyes have a selective action on different kinds of tissue — so that the doctor or biologist can distinguish different bacteria, nerve tissue and other minute details of structure by the different colors that they take on when stained.

Sir William Perkin's chance discovery of mauve developed, in a short half century, into an industry worth fully $250,000,000 yearly. Germany alone exported about $90,000,000 worth of dyestuffs yearly before World War I. Two great companies had a number of large plants, in each of which there were employed from 100 to 400 chemists, and more than that number of other technically trained men. It was partly the extensive research organizations built up by these companies, and partly the rather ruthless methods of competition designed to prevent the development of a competing industry in other countries, that gave Germany her pre-eminent place in this field prior to the war, in spite of the fact that England gave birth to the industry and France contributed most to its early development.

The influence of World War I on synthetic chemistry outside Germany

World War I, however, made the United States and many other countries realize their unfortunate position in not having a well-developed synthetic organic chemical industry within their borders. Not only dyes, but important drugs, perfumes and many other necessary organic chemicals were practically unobtainable during the early years of the war, and only the most intensive chemical research and development work prevented much more loss and suffering than that which actually did occur. But the economic factor was not the only one involved. It was now realized that a flourishing organic chemical industry is essential for the security of a nation, especially in view of the close relation of this industry to chemical warfare, which played such an important part in World War I.

After the war extensive German patents in the organic chemical industries were seized by the United States. These patents were taken over by the Chemical Foundation, which issued licenses to American manufacturers to operate under them. America's research chemists took full advantage of the unparalleled opportunities that were thus opened to them. With surprising rapidity American organic chemical industries developed a full line of the best dyes and drugs. As time went on, they also turned to the manufacture of a bewildering variety of plastics and other products. The other big industrial nations of the world also fostered the development of their synthetic chemical industries. Germany never regained her former supremacy in this field.

Other interesting and valuable products of the once despised tar barrel

But the making of dyestuffs is far from being the only way in which the synthetic chemist outrivals nature itself. The endeavor to make synthetic quinine, which had as one result the discovery of mauve, also gave rise to another enormously important industry — that of synthetic drugs. The drug business has undergone a remarkable evolution due to the synthetic chemist. Formerly, practically all drugs were obtained from herbs, plants, trees, etc., which grow in various parts of the earth. Naturally the strength of the drugs obtained from different sources varied widely, and yet it was almost impossible to determine their relative strength. Efforts at analysis were almost hopeless — each extract or essence con-

tained a score of unidentified compounds, and no one knew to which one the drug owed its desirable properties. Some of the most necessary drugs were very rare, expensive and difficult to obtain. But more important than that, all the natural drugs ever known did not contain more than a few thousand different compounds, and many of these were practically unavailable because present in such small quantity, or because they were associated with other poisonous compounds so that their medicinal value was never discovered.

The purity of the synthetic product greater than that of the natural

It is easy to imagine, then, the change which has come about since over two hundred thousand pure organic compounds have been prepared. There is scarcely one of these but has some definite physiological effect if taken in the proper quantity. One by one they have been tried out for the cure of different diseases, and slowly there has arisen a new science of medicine. The essential element in a great many of the natural extracts has been determined, and prepared in a high degree of purity. Often the natural product is cheaper than the synthetic, but even in these cases the synthetic chemist has been of assistance in setting up standards of purity and methods of determining the strength of any given sample. In many other cases the pure synthetic article has completely driven out its rare or uncertain natural rival. But far more important than these is the host of invaluable new remedies which the chemist has given us. Indeed, many of the most trusted remedies in the modern physician's handbag were unknown compounds twenty or thirty years ago.

New remedies the gift of the chemist to suffering humanity

Among the most important of these new remedies are antipyrin, phenacetin and acetanilide, the fever specifics; piperazine and lysidin with their solvent powers for uric acid; sulphonal and veronal, with their sleep-producing powers; stovaine, novocaine, two of the many new anæsthetics — and a host of others too numerous to mention here. One more example may, however, be of interest — concerning the valuable and powerful drug adrenalin. It is a physiological agent so powerful that the injection of one-millionth of a gram (one-thirty-millionth of an ounce) for every two pounds of weight of an animal will cause its blood pressure to sustain a column over seven inches higher than normal. Indeed, one-two-millionth of a gram will produce distinct physiological results in an adult man; the small doses of homeopathy are thus gigantic as compared with those of adrenalin. The drug makes possible bloodless surgery, and prevents the shock to the patient which usually follows an operation. Adrenalin has in the past been obtained from the suprarenal glands of oxen. The synthetic chemist has learned to produce it, and for some time now this most powerful drug has been recognized as a particularly useful coal-tar by-product.

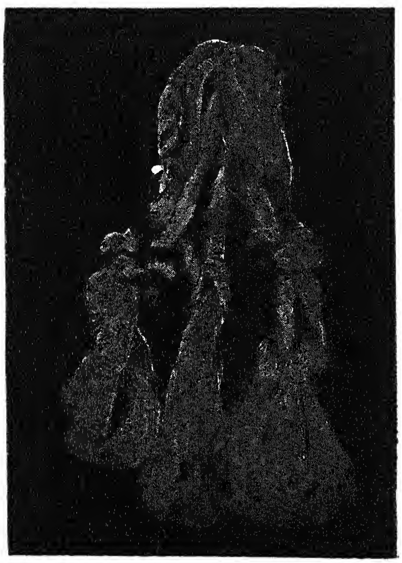
The chemist's delicate flavors and perfumes rival those of nature

Natural flavors and perfumes are also compelled to submit to the competition of artificial products derived from coal tar. Vanilla, the delicate essence extracted from the vanilla bean, has been largely supplanted by synthetic vanillin, which is exactly the same substance. The flavors and odors of apples, pears, bananas and many other fruits are reproduced either by making the identical flavoring substance, or one with similar properties. One of the most wonderful artificial scents is ionone, which has an overpowering smell of fresh violets and forms the basis of all violet scents. It is so powerful that a drop so small as to be scarcely visible will perfume a whole house for days.

From a scientific standpoint the production of attar of roses and heliotrope is even more remarkable. About twenty distinct substances unite to compose that precious scent, attar of roses, but the chemists of the great perfume factories of Leipzig succeeded, after laborious and costly research, in separating these components, identifying each one, making each artificially, and then reuniting them in the

exact proportions occurring in the natural product. Even the most sensitive and well-trained nose cannot distinguish between the natural and the artificial attar of roses. Jasmine is another odor which has been prepared in a similar manner, though its components are fewer and better known. The analysis of this valuable essence is said to be as follows:

SUBSTANCE	PER CENT
Benzyl acetate	65.0
Linalol	15.5
Linalyl acetate	7.5
Benzyl alcohol	6.0
Jasmone	3.0
Indol	2.5
Methyl anthranilate	0.5
	100.0



A SKEIN OF ARTIFICIAL SILK (RAYON)

But perhaps most surprising of all is the success which has attended the chemist's effort to make artificial textiles, and artificial silk in particular. The comparative simplicity of structure of this most costly and beautiful of fabrics long ago aroused the hope that it might be duplicated by artificial means. Nor were these hopes vain, for within the past twenty years there have been perfected several commercially successful processes, a description of which is given in the next chapter of this section. In fact, many of the silk fabrics now bought have never had even a speaking acquaintance with a silkworm.

It is difficult to foresee the limits of synthetic chemistry. Some few men, indeed, maintain that there are no limits of which we can know — that as soon as we learn sufficient chemistry, we will be able to produce everything which is now produced by the living forces of nature — and perchance may some day produce life itself. One thing in particular makes it probable that the chemist of the future will be able to make many compounds which have baffled scientists in the past — because chemists have discovered the importance of "catalysis" in chemical reactions.

It must be admitted that the ordinary procedure by means of which a chemist imitates the processes of nature is very crude. He has to use great heat and violent methods to produce the substances that plants and animals manufacture in a gentle and natural way. For a long time he was quite at a loss to discover how a microbe could transform one form of matter into another without the powerful apparatus of a chemical laboratory. But at last he found out that certain substances, in extraordinarily small quantities, have the power of provoking great changes in large mixtures of various kinds. For instance, one-10,000,000,000th part of a thimbleful of blue vitriol will bring about a reaction between certain substances. Finely divided platinum is a catalyzer with a large range of action. Merely one-16,000th of an ounce of it will reduce a pint of the bleaching mixture of hydrogen peroxide to water and oxygen. If, on the other hand, the platinum is mixed with hydrogen and oxygen, it will turn these two gases into water without any heat.

And the marvelous thing is that, when the water is formed, the platinum is ready to produce over and over again the same effect. It is not worn away or diminished in power by the strong and large reactions it produces in mixtures of other elements. Suppose, by scattering a few handfuls of some new substance over one of our big cities the whole of it could be changed into a liquid mass. That would be on a large scale a catalytic reaction such as chemists

are now able to produce on certain compounds with a marvelously small amount of the catalyzing substance. By finding a satisfactory catalyzer it is possible to bring about with comparative ease changes which are otherwise almost impossible to produce. The proper catalyzer is, however, often hard to find, and in many cases is only discovered by accident. The discovery of the effect of mercury in the indigo synthesis, which we have mentioned before, is a case in point.

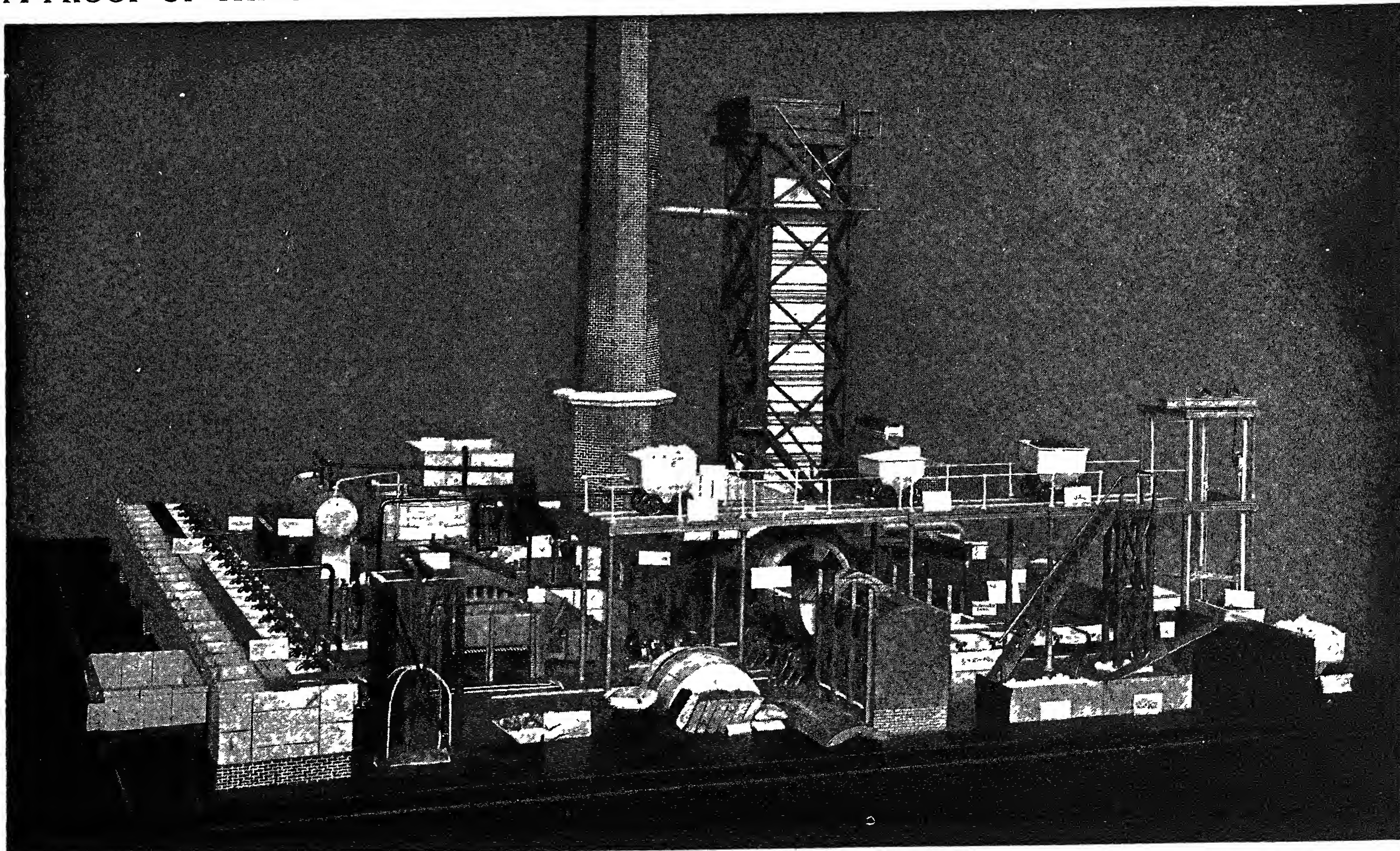
Catalyzers have been found to be of especial importance in trying to duplicate the products of living nature. As a matter of fact, chemists have found in the bodies of plants and animals substances that work in somewhat the same way as platinum does.

Merely by their presence alone these substances convert one kind of compound into another. For instance, there is something in yeast which has the power to transform 200,000 times its weight of sugar into another substance. Again, rennet will change 400,000 times its weight of soluble casein. All the kinks and corners of the bodies of plants and animals have these efficient little chemical substances, which, at the right time and the right place, exert their catalytic power on the juices of the organisms. Moreover, once having discovered these catalytic agents, the chemist is frequently able to reproduce them in his own laboratory — often, as was the case with adrenalin, starting from coal tar.

Getting nearer to the mystery of life, the chemist has discovered that there are anti-catalyzers, which prevent the action of the real catalyzers. It seems extraordinary to talk about poisoning a metal, but that is practically what an anti-catalyzer does. A little prussic acid, for instance, will take away the powers of platinum, and prevent it from doing its work. There is an interesting similarity between this occurrence and the poisoning of the living cell by the same deadly acid. On the other hand, the living body often manufactures a small quantity of some poison by means of which it retards, when necessary, the action of its natural catalyzer. There are no poisons, it has been well said, but merely poisonous effects. But sometimes the control is effected by making two catalyzers which only act when they come together. So much progress has been made in the study of catalytic effects that all the problems relating to the chemistry of life have become very complicated. It will require the work of generations of chemists to analyze into their elements all the catalytic substances found in living tissues; and very likely a still longer period of time will pass before these substances have been manufactured in a laboratory. On the other hand, Professor Fischer succeeded in manufacturing artificially some of the proteids of protoplasm, which is the physical basis of life. And it is known that all the main reactions in the living processes of digestion and respiration, the conversion of food into tissue, and the elimination of waste products, are governed by catalytic influences.

Yet few modern chemists are now bold enough to prophesy, with Berthelot, that life itself will one day be found in the tube of the man of science. It is true that the chemist can now create more substances than the life-force can manufacture in plant and animal. It is true also that he has reason to believe that the principal manifestations of what we call life are nothing but complex products of innumerable chemical reactions in the living substance of protoplasm. On the other hand, the modern chemist is filled with awe at the infinite adaptability and delicate and subtle strength of the lowliest of living things. He cannot deny the existence of a spiritual entity abiding within the body and directing its activities, without adding to the sum of actual material energies. The idea of life as a mere mechanism is completely exploded. And if, after all, man at last succeeds in unveiling the mystery of the material garment of the spirit of life, it will surely be by reason of the soul within him, with its high, pure, disinterested passion for knowledge, for it is this spirit which has inspired almost every step of his progress as a serious rival of nature.

A PROOF OF THE COMPLEXITY OF THE PROCESS BY WHICH CHEMICALS ARE CHEAPENED



A MODEL OF THE PLANT FOR THE MANUFACTURE OF SODA BY THE LEBLANC PROCESS, DISCOVERED IN 1790

ON GROWING OLD

The Developing Science of Geriatrics

by

HELEN MERRICK

"GROW old along with me, the best is yet to be," sang Browning in a blithesome mood; and the idea of at least growing old gracefully has been with us for a long time. Some few men and women achieve the feat, loved and honored by younger generations as well as their own. For all too many others, however, old age is dreary, unsung, useless and beset by infirmities. Yet we know today that the later years can be made rich and productive.

One tool in this effort is geriatrics, the branch of medical science concerned with human old age and its diseases. "Geriatrics" comes from two Greek words meaning "old age" and "healing." In discussions of aging, you may hear a broader term, also from the Greek—gerontology. It means the study of aging, not only in human beings but also in other living creatures and in such non-living substances as crystals.

No one would deny that to make old age brighter is a worth-while aim. There are other reasons, however, for the growing importance of geriatrics to society as a whole. In countries where the standard of living is high, more men and women than ever before are living to a ripe old age. In fact, in such countries as the United States the elderly group is increasing more rapidly than any other. Two thousand years ago, in the Roman Empire, the average length of life was only 23 years, hardly past youth. In the United States around 1900, the average was 47. But consider how life expectancy has leaped within our own century. In 1948 the United States average was 67, a gain of 20 years; and for a special group —white women—it was 71, passing the Biblical three score years and ten. Between 1900 and 1950, the total population of the United States almost doubled, but the group 65 years or older quadrupled, from 4 per cent of the total in 1900 to 8 per cent in 1950. In some states, such as New Hampshire, the group made up as much as 10 per cent of the population. By 1975, it is estimated, 11 persons in every 100 in the whole of the United States will be 65 years old, or older.

The tremendous gain in life expectancy has come about largely because many of the hazards of childbirth and youth have been practically conquered. One-fifth of the babies born in the United States around 1900 died before they were old enough to go to school. Today, if a child reaches his first birthday, he will almost surely reach high-school age. Diseases that attack youth come for the most part from outside the body, carried by microorganisms. With the tremendous improvements in sanitation and medicine's victories over many infectious illnesses, a much greater number of people are surviving into middle and old age. Medicine has still to win a like conquest over the chronic diseases, which begin silently within the body and are a much greater threat in the later years. Some scientists believe that if human beings could enjoy complete freedom from disease, the normal life span would be as long as 125 years.

The profound shift in the population structure has far-reaching implications. The economic aspect alone has tremendous importance because so many elderly persons have not been able to support themselves. In a recent year about one-third of the aged in the United States had no cash income at all, and only 10 to 20 per cent of those reaching the age of 65 had enough

Black Star

Advanced years hold no terrors for this skillful typist, who finds contentment in being useful.

savings to be financially independent. Figures for old-age assistance, to which both the Federal Government and the states contribute, reflect the problem sharply. In 1939 the benefits amounted to only $601,000,000, but by 1950 they had risen to $2,735,000,000. If present trends continue, it is likely that by 1975 support of the aged will cost the Federal Government $15,000,000,000 a year.

We begin to age from birth, and even before, and it is all gradual. Youth does not depart and age arrive at the stroke of midnight on a particular date. The organs of the same person age at different rates. Furthermore, the rate of biological aging varies widely among individuals. Some persons ward off amazingly the effects of old age. Thus, in one study of old people without disease, comparatively little impairment of bodily organs was found although the subjects were a hundred and more years old.

There is, however, a hazy dividing line on one side of which an organism is considered young and on the other side of which changes appear that indicate aging. Throughout life there is a building-up (growth) and a breaking-down (atrophy) going on in most of the tissues. Youth is in the ascendant as long as the rate of growth is greater than the rate of atrophy.

Some living things are truly immortal—the one-celled organisms which, when they grow to maximum size, simply divide to form two new young individuals. In one experiment a single amoeba went through two hundred successive divisions and was still multiplying merrily at the end of thirteen months. One of the strangest facts of all is that under ideal conditions, living material that ordinarily would age and die will remain young far past its usual span. The most famous experiment to prove this is the one begun by Dr. Alexis Carrel, of the Rockefeller Institute, in 1912. He took a bit of heart tissue from the embryo of a chick and placed it in a nourishing solution. Care was taken that the necessary kind of food (from other embryos) was provided regularly, waste was disposed of and no bacteria contaminated the solution; and from time to time the tissue was trimmed. It lived and grew until the experiment was deliberately ended in 1946, a period of thirty-four years, though the normal life span of a chicken is about fourteen years.

All the symptoms of aging can be summed up as a gradual decline in the body's powers of self-renewal. Gradually bones lose their mineral matter, which is replaced by fibrous material. They become brittle and knit more slowly after a break. Tissues become drier and more fat seeps into them. It becomes harder for the body to regulate its temperature and to maintain its chemical balance. The senses lose their keenness although, except for some loss of focusing power, the eye is good for 125 years. Also on the credit side of the ledger is the fact that the lungs and the digestive system alter comparatively little with age.

It is the heart and the blood vessels that first succumb to aging. In fact, breakdowns in the circulatory system account for almost two-thirds of the deaths after the age of sixty. The course of such breakdowns usually begins with deposits of calcium in the heart and arteries, followed by loss of elastic tissue in these organs, high blood pressure, heart strain, burst capillaries, blood clots and, finally, failure of the

circulation. The brain, nervous system and kidneys might hold out indefinitely were it not for the failure of the complicated circulation that supplies them. This seems to bear out the old saying that a man is as old as his arteries. Yet hardening of the arteries alone is too special a condition to use as a measure of physical age.

Dr. John H. Lawrence, of the University of California, discovered what seems to be a better measure—that a man is as old as his ability to get rid of nitrogen gas from the blood. At sea level about one thousand cubic centimeters of nitrogen gas are dissolved in the body fluids of an adult. The total amount stays the same but the fluids

Black Star

There is no substitute for the trained eyes and hands of an expert carpenter, regardless of age.

constantly eliminate the nitrogen molecules they have and take in new ones during breathing. In his experiments, Dr. Lawrence had a group of people of all ages inhale small quantities of radioactive nitrogen as tracer material. He then determined how fast the subjects eliminated nitrogen by collecting the gases breathed out and counting the tagged nitrogen atoms with a Geiger counter. Youngsters of fifteen eliminated half the gas in a few minutes, while persons sixty-five or older took as long as five hours. Another indication that nitrogen-elimination rate is a measure of physical fitness was shown by the fact that subjects in poor physical condition had abnormally slow turnover rates.

What aging does is fairly self-evident, but the reason (or reasons) for the decline still eludes us. As Dr. Edward J. Stieglitz puts it, we either wear out, from use, or rust out, from disuse, with abuse playing a part as it encourages degeneration. Dr. Stieglitz believes that the answer lies hidden in the matrix, the complex non-living material in which the body's cells are bathed. It holds the elements of the cells together, supports them, brings nourishment to them and carries waste away. The most familiar form of the matrix is the plasma, or liquid part, of the blood. It is essential to life that the chemical balance of the matrix be maintained within narrow limits; and with age, the mechanisms that control this balance grow slower and react with less vigor.

Reasoning along somewhat similar lines, many biologists suspect that enzymes have much to do with the aging process. Enzymes are exceedingly complex molecules. They seem to be protein compounds, with nitrogen as an important element. They are largely built up out of vitamins and minerals, and they act as catalysts in the various chemical processes of the body. That is, they must be present for the chemical reactions to take place, though the enzymes themselves remain little changed or not at all. Without enzymes, no vital process can continue. Consequently, reduction or destruction of enzymes or a loss in their power could account for the symptoms of aging. The little work that has been done along these lines so far does indicate that with age the efficiency of the enzymes decreases. However, most of the research on enzymes has been concerned with identifying them in various chemical reactions and with studying how they work. Discovery of how enzymes change with age therefore would seem to offer pioneering opportunities to scientists.

The foregoing ties in closely with what has been learned about nutrition in relation to later years. Nutrition experts are interested in learning how well food (including

oxygen and water) is absorbed and used by the body as well as the kind and amount of food consumed. They believe that what we eat is closely related to the rate at which we age. By the time many persons reach the age of sixty, their bodies are poor in calcium, iron, protein, vitamin A and the B vitamins, and these deficiencies have been built up over years. Calcium alone is a sort of jack-of-all-trades in the body. It is essential to bones and teeth, in heart action and blood clotting. If the blood does not get all the calcium it needs from food, the blood takes what it needs from bones until they become as brittle as toothpicks. Anemia results, with a loss of muscular strength and lowered resistance to infections, if the body does not get enough protein. Without iron, the best source of which is red meat, the blood cannot carry life-sustaining oxygen to the tissues.

"The thin rats bury the fat rats"

The foods the older person does *not* need so much of are sugars and starches and fats. Cake and candy and gravy merely add pounds of fatty tissue that must be supplied by extra miles of blood vessels, adding undue strain to the circulatory system. As the famous experiments on rats conducted by Dr. C. M. McCay, at Cornell University, proved, the "thin rats bury the fat rats." Ordinarily, a rat reaches full growth at 4 months, it is elderly at 2 years and dies before 3. By feeding a group of rats a diet that was low in calories but had enough vitamins and minerals, the period of growth was extended from 4 months to as long as 1,000 days. In one experiment, the last senile survivor of a group receiving the usual kind of food died at 965 days, though at the same age the animals with a low-calorie diet were still bright young adolescents. Their whole life span was the equivalent of a human life span of from 100 to 150 years, and they were seldom diseased and were much more energetic in every way than their brothers on the usual diet.

Overweight in later years carries other penalties. In addition to the strain on the circulatory system, it is associated with gall-bladder disturbances, hernias and diabetes. In fact, 80 per cent of the cases of diabetes in adults are connected with over weight.

What, then, *is* a good diet for the later years? In general, it should include a high level of proteins, a low level of fats, only a moderate amount of sugars and starches, and higher than average amounts of minerals and vitamins. In terms of breakfast, lunch and dinner, this means: eat plenty of vegetables, fruits, lean meats, fish, cottage cheese and eggs; eat lightly of cereals, fats and sweetened fruits; shun concentrated sweets and alcoholic beverages. One quart of milk a day will supply calcium needs. (It is the thinner part of milk, the whey, that contains calcium.) However, ordinary milk contains considerable fat and other undesirable ingredients for older people. There is now a milk on the market, called "geriatric special milk," that is high in protein, low in fat and rich in calcium, iron, vitamins and other wanted materials.

As we said earlier, there is still tremendous variation among individuals in the rate at which they age and the course aging takes. No two persons who have lived a century or more ever give the same recipe for longevity. One centenarian will say that he has never smoked; and another, with impish relish, will state that he has smoked like a house afire all his life. So we cannot get away from the fact that some persons inherit stronger constitutions than others. Long life runs in certain families. At the same time, if many of the chronic illnesses that afflict the aged were detected early, they could at least be brought under control if not cured. Unlike the diseases that are more prevalent in youth, which are of short duration, the chronic diseases, as the name implies, are lingering and often result in complete invalidism. The best safeguards against them are thorough periodic examinations, even when the person feels well.

Aging affects the mind as well as the body. There seems to be a very slow decline in learning activities after the age of twenty; at least the speed of learning decreases. But if the factor of speed is re-

moved from intelligence tests, older persons do as well as younger ones, with one important exception. This is that anything that is entirely strange or that upsets established habits is likely to be far more difficult for the elderly. Perception has become slower and the mind cannot unlearn old ways as easily as when it was younger. However, because of the greater grasp gained through experience, many persons past sixty, and even some over eighty, actually surpass in particular skills or capacities the average person of their own sex in the prime of life. The skills that are kept in practice do not decline like those left unexercised. Verdi composed FALSTAFF at the age of 80; Oliver Wendell Holmes was in service on the Supreme Court bench at 90; Titian painted Christ Crowned with Thorns at 95. Granted that these were exceptional men, it is still true that years alone need not dull the highest powers of the human organism.

It follows that for society to discard the skills of men and women just because they have reached a certain birthday is a tremendous waste of assets. It is also a tragedy for many of the workers themselves, not only from an economic standpoint but also because it is a symbol of the end of independence and purpose in life. Many of these people later become truly unemployable simply because they have not been employed.

As far as income is concerned, various union-management programs and social-security provisions alleviate the situation somewhat, but these are not final answers by any means. Under private pension plans that pay flat monthly sums on retirement, businesses that hire older workers face a heavier future-pension liability. This may result in a refusal to hire older workers. One plan has been put forth by which the question of retirement would be decided by the worker as he reaches the age of 62 to 68, at which his pensions would become payable. From 68 to 72 retirement would be decided by the union and management; and after that it would be at the option of management.

What needs to be done is to judge the worker on the basis of health, ability to produce, emotional attitudes and personality, and not on his calendar age. Aptitude tests for those over sixty have been suggested, as have factories especially built for older workers who may have a slower reaction time and less stamina but perhaps more patience. At that, many older workers hired in wartime proved that they were capable of splendid production records.

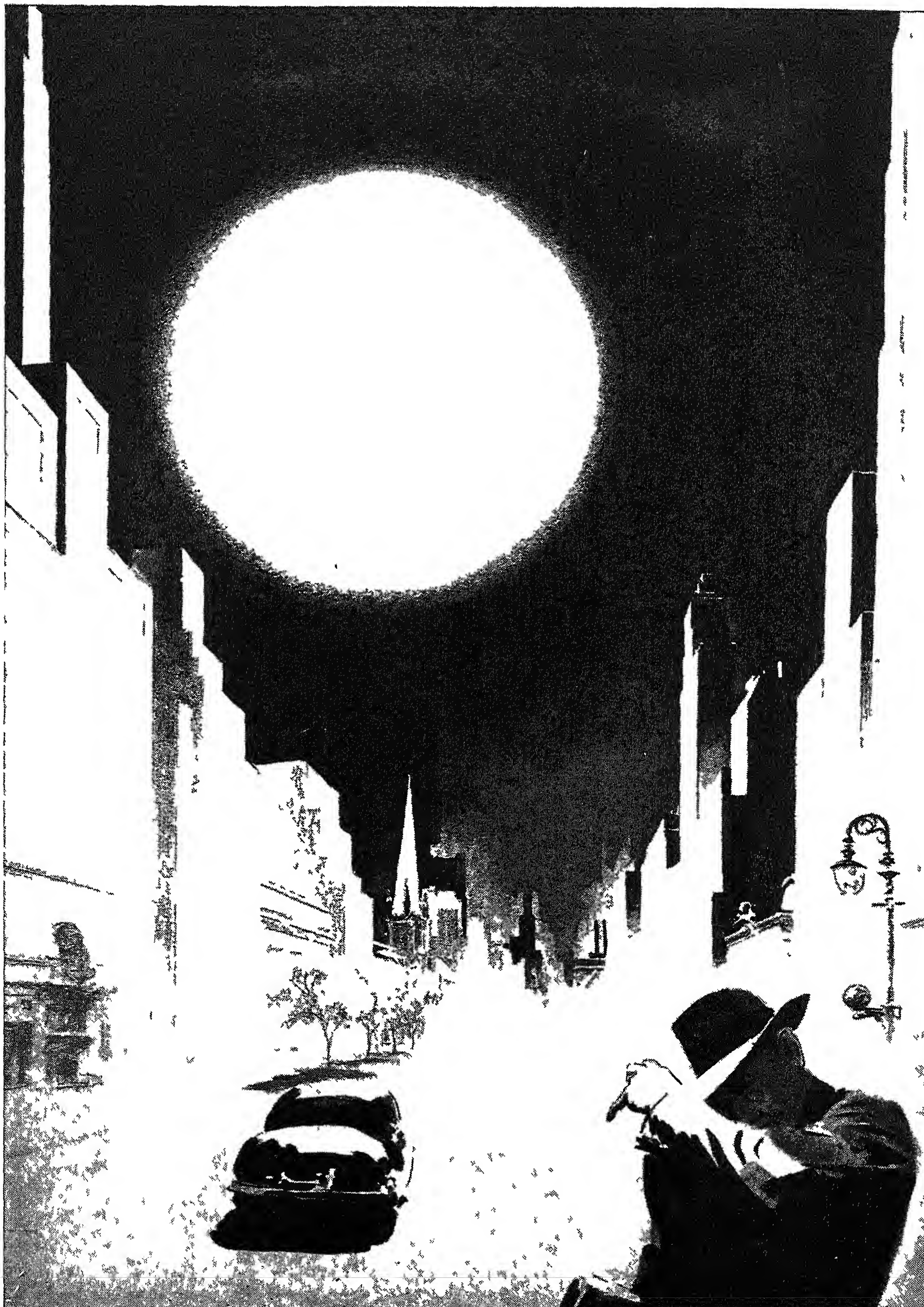
A needed change: to place greater value on maturity

From the days of the pioneers in North America, the highest value has been set on the period of youthful vigor. We must change this attitude and place greater value on maturity if we are to cope effectively with the economic problems of the aged.

Interwoven with the basic requirements of good health and economic security for satisfactory later years are many other considerations. Older people need opportunities for play as well as work; they need to give affection and have it returned just as much as younger human beings do. Nor does the creative urge lessen with age. In fact, there is no better insurance against boredom in old age than to have acquired an avocation or a hobby in youth or middle age. Many communities are meeting the need for recreational activities by developing special clubs for the aged. A typical center of this sort is self-governed and is open all day. The members work at various arts and crafts, chat together, edit their own magazine and plan monthly birthday parties and other entertainments. Many older persons have found new interests, and often new friends of their own age, in adult-education classes. Special housing projects for the aged have also been developed.

In this article we have been able to touch on only a few of the many aspects of geriatrics. Questions have been raised that perhaps only years of research can answer. Nevertheless, since so many of us today can look forward to a long life, it is reassuring to know that science has brought up its big guns and is training them on the field where the battle for healthy, active later years will be won.

AN OMINOUS BALL OF FIRE



At the instant of the explosion of an atomic bomb a brilliant fireball appears in the sky, deadly heat and radiation spread out from it in all directions. A shock wave, caused by the expansion of hot gases from the explosion, sweeps over the area, accompanied by winds of up to 800 miles an hour

IF THE ATOM BOMB STRIKES

What to Do Before and After an Attack

YOU who read this may never have any occasion to protect yourself against bombs of any kind, atomic or otherwise. Nevertheless, since that summer day in Hiroshima, back in 1945, there has been and probably always will be the possibility of other such air raids. In Canada and the United States, radar networks and airplane spotters have been organized to detect hostile planes and to prevent sneak attacks from the air or from the sea. Most towns and cities have air-raid sirens to warn the people that raiders have been detected. In spite of these and other precautions we have to recognize the fact that hostile planes might evade our defending forces and drop a bomb before a warning could be sounded.

The most likely targets would, of course, be the big industrial centers, important seaports and railroad centers, but even the people who live in small towns or in the open country should learn what to do if a bomb should be dropped near by. The chance of such a thing happening to a little rural community may be one in several million, but it is still a chance. For one reason, raiding planes sometimes lose their way, especially in wartime when blackouts help to obscure landmarks. This happened many times during World War II, to both Allied and German bombers. Then, too, the defense may be so active that the raiders have to unload their bombs in a hurry, anywhere they happen to be. In the case of an atom bomb, atomic clouds may drop ashes hundreds of miles away from the place where the explosion actually occurred. Another thing to bear in mind is that even if you live in a secluded valley miles from anywhere, you may go to the big city to shop on the very day that the enemy selects to raid it. All in all, there are several excellent reasons why every man, woman and child, no matter where he or she may live, should learn what to do if a bomb strikes.

Naturally your chances depend somewhat on where you are in relation to the center of the explosion. This is so where any kind of bomb is concerned—even a homemade hand grenade—but it is especially so in the case of the atom bomb.

An atomic bomb may be exploded in the air above the target, or on the ground, or in the water of a harbor. The most likely of the three kinds of attack would be a bomb exploded in the air, about 2,000 feet from the ground, since its blast effects would be far more destructive than those of a ground or water explosion, though it would not release so much radioactivity.

In the case of an air burst, at the exact instant of the explosion there is a terrific flash, and a fireball appears which rapidly grows until it is about 900 feet in diameter. This fireball is a hundred times as bright as the sun, and from it deadly heat and radiation spread in all directions. The heat flash is dangerous up to 2 miles, but the radiation intensity lessens rapidly after 4,000 feet (about four-fifths of a mile). Half of the radiation passes off within the first second, and in three seconds the heat and most of the radiation are over.

After the flash, a tremendous shock wave sweeps over the area. This is caused by the expansion of hot gases from the explosion, and it is accompanied by winds of about 800 miles an hour. The winds drop to about 100 miles per hour within a mile and a half. Several seconds after the outrushing wind comes an inrushing wind about half as strong as the outgoing wind. At the end of 10 seconds, the immediate danger from the actual explosion is over.

If you are above ground anywhere within three-quarters of a mile from the air burst, your chances of survival are less than fifty-fifty. If you are underground in this area

Wide World

If the proposed hydrogen bomb burst in Manhattan, as shown here, most buildings within the inner circle above would be flattened; people without cover within the outer circle would be in grave peril.

your chances of coming through are good, unless you are almost directly under the explosion point of the bomb.

Within a half mile of the explosion, it is estimated that complete devastation would occur. From one-half mile to one mile, only concrete and steel-frame buildings would stand. The rest would be gutted or destroyed. From one mile to a mile and a half, steel-frame buildings would be severely damaged and there would be great danger from flying debris. Most old-fashioned brick and frame buildings would be destroyed. Radiation would no longer be a danger, but the heat flash, though no longer deadly, would be dangerous.

As in all kinds of bombing raids, many fires would break out, most of them caused by electric short circuits, broken gas mains, oil lines and gasoline tanks. The bomb's effects would become gradually less up to a distance of four or six miles, and glass and plaster would be broken within a radius of eight miles from the center of the explosion. Strong winds would spread the fires that had already been started.

When an atomic explosion takes place on the ground or in the water, the heat, the

blast and the direct radiation do not reach nearly as far as in an air explosion. In a water burst there is very little heat and direct radiation, and the shock wave does not reach more than a mile. There is, however, another hazard to the ground and water bursts which is not present to any extent in an air burst. They throw up great clouds of spray or dust which become highly radioactive. These clouds drift with the wind and contaminate objects in their path. People who are exposed to them for too long are poisoned.

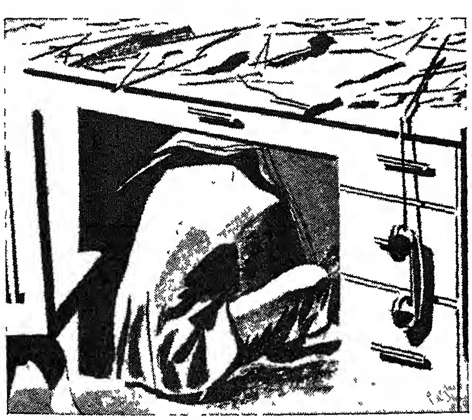
Now let us see what to do if such a bomb does drop near us. If the raiders are detected the air-raid sirens will warn us in plenty of time to take the proper precautions. Even if the attack is unexpected, however, there are several things that you can do to protect yourself, even if you are not in a place where there is shelter.

The first warning you will get will be the blinding flash of the explosion. When this comes, no matter where you are you must close your eyes and, if you are in the open, fall to the ground, face down. If you are near a building get as close to the wall as possible. That is the safest place to be when bricks and stone begin to fall from higher up on the building—they always land a little way out from the base of the wall. Cover your head with your arms or with anything you happen to be carrying, such as a coat or even a brief case. If you are near a doorway when the flash comes, step inside, but only if it is just a step or two away. When you get inside, move to the right or left, away from the opening, and cover your face and any other exposed parts of the body.

If you are indoors, at home or in a store or office, dive under a bed, table, desk or counter—any article of furniture that will protect you from flying glass and falling plaster. Keep as far away from the windows as you can and cover yourself with anything within reach—a rug, cushions, even a typewriter cover if nothing else is handy. If you have a choice, cover yourself with something white or light in color.

If you are out in the country or in a park where there are trees, crouch down behind the nearest tree, turning away from

If caught in the open, crouch behind a tree. Turn away from the blast and cover skin that is exposed.



If at home or in an office, crawl under a table or desk to avoid heat-flash burns and falling plaster.

If in a city street, fall flat close to a wall in order to avoid falling rubble; cover your head.

Men utilizing special detectors will locate radioactive areas in order to warn you away from them.

If a bomb has burst under water within a mile of your dwelling, bury all clothes, drapes and so on.

the flash and, of course, covering your face and hands.

The city or town in which you live will have its Civil Defense Regulations and an organization in which officials as well as citizens have their part. When enemy planes are detected coming toward your city the sirens will signal the Alert. It may be that the enemy's target is a place many miles farther on, but every town over which the raiders fly will be alerted. When you hear the rising and falling note of the signal, get busy immediately, but do not get panicky. Go to the nearest air-raid shelter or into the basement if you have not the time to reach a regular shelter.

If you are riding in a taxi or bus, get out and look for shelter. If you are driving your car, park at the curb, but not in any spot where the car will block a street or a corner. Leave your keys in the car and close the doors and windows. This will help to keep out radioactive dust and bomb ashes. If your car does not get damaged by the blast or the heat of the bomb it will run, for radioactivity does not hurt the fuel or the ignition system or the tires or any other part of the car.

If the light and gas companies in your city are organized to cut off these utilities over the whole area, you need not bother to cut them off in your own home. It would be well, however, to turn off all pilot lights; otherwise you might forget them later when the gas in your area is turned on again. The blast may cause dislocations in pipes or wiring and start fires. For this reason you should put out any fires in stoves or fireplaces. If you have an oil burner, turn off the blower motor and then shut off the feedline valve. Then shut the doors and windows, pull down the blinds and go to your shelter or basement.

When the All Clear is sounded you can come out, if the explosion was an air burst. The immediate effect of the burst is over in a few seconds, as we mentioned earlier. Be careful, though, to look out for falling wreckage. When the attack is over, the worst danger is from fires. Don't let yourself be trapped by a big fire, but at the same time, make sure that any little fires which may have started in your home are put out. Chemical fire extinguishers and even buckets of sand, if used promptly and thoroughly on a small fire, may help to prevent a disastrous big fire.

If fire or damage makes it necessary for you to leave the building you are in before you have received the official signal and there are clouds of dust or spray outside, put a cloth—even a handkerchief will do—over your nose and mouth so that you won't inhale any radioactive substances. It may very likely be that the dust is merely the result of wreckage, but it is best not to take any unnecessary chances, for the dust might be radioactive.

All wash drawings, N. Y. State Civil Defense Commission

A good scrubbing after an atom-bomb blast will remove radioactive particles clinging to the skin.

As we have mentioned before, an air burst is the type of explosion that is most likely to be experienced, and it has been found that such bursts leave hardly any lingering radioactivity. Fire fighters and rescue squads can move promptly toward the center of destruction with little fear of harmful radiation.

If, however, you have been officially notified that the explosion was a ground or water burst, don't use any food or liquid that has been exposed. Canned goods and bottled beverages are quite safe. As soon as possible after a water or ground burst, specially trained teams with Geiger counters to detect radioactivity will find the areas that are badly contaminated, and the people in those areas will be sent elsewhere. If you are sent away from a contaminated area, take a bath or shower (with plenty of soap) as soon as possible, and change your clothes. Contaminated clothes, drapes and so on should be buried.

There is no way of knowing right away whether you have been exposed to radiation, as you do not feel anything when it hits you. Symptoms of radiation sickness show up later on, the length of time depending upon how much radiation you have absorbed. If you have absorbed a great deal, you will know it in a few hours. The first signs are nausea and shock. In the first day or two the shock will be followed by vomiting, diarrhea and fever. You will not feel any pain, but you will suffer discomfort, depression and fatigue. This will go away, then return for a few days. In the *worst* and *untreated* cases, death follows.

In moderate cases the symptoms may not appear for several days or weeks. Sometimes they will go away entirely for a time and return later.

What to do if you show signs of radiation sickness

If you show any signs of radiation sickness, go to a medical station at once. If conditions after the bombing prevent you from getting proper medical treatment immediately, there are some simple rules to follow until help comes. Keep warm. Get complete rest; stay in bed if possible. Drink warm, nourishing liquids, and eat foods rich in sugar and protein, but do not eat or drink foods or liquids that have been exposed in a contaminated area.

Perhaps the most important thing of all to remember is to keep calm and think of other people's comfort and safety. When the raid is over and people are needed to carry on rescue and fire-fighting work, do your share. In order, however, to make your efforts really count in an emergency, you should offer your skills and services to the Civil Defense authorities long before there is any imminent danger of their being needed.

There is need for many volunteers to aid in civil defense

Your community no doubt has already provided for the training of volunteers in many activities. Both men and women can serve as medical workers, air-raid wardens and Geiger-counter crews. For fire fighting, heavy rescue work, street clearing, rebuilding and police auxiliary work, men are needed. For car driving, child care, hospital work, social work and emergency feeding, there is a need for women volunteers.

Courage, common sense and co-operation can be shown by all of us, not only during the actual emergency, but in the long and sometimes tiresome training that will fit us to do our part if an attack comes.

IN THE EARLY DAYS OF LIFE'S PILGRIMAGE

Harold M. Lambert, from Frederic Lewis

This little toddler has made a promising start toward the goal of full growth and development.

THE SAGA OF HUMAN LIFE

The Annals of Growth, Development and Decline

by
BENTLEY GLASS

THE Chinese, who reckon that a person is one year old at birth, are nearer right than we are. Birth is not the beginning of life; it is only a change in the conditions of life, in the environment that surrounds the individual. It is a rather radical change, to be sure. Yet the growth and development that go on after birth are but continuations and alterations of processes that went on before that time in the embryo and fetus. The saga of human life really begins when the egg is fertilized in the womb.

The role of heredity and environment

At this real commencement of life, the inherited pattern of a person's growth is fixed, once and for all. Each of the two parents has contributed to the child a set of twenty-four chromosomes — threadlike bodies within each cell. These microscopic threads carry the thousands of genes that determine one's hereditary nature. There are genes for long life, for the color of the eyes, for the shape of the nose, for the size of the feet; genes that promote normal blood clotting; and innumerable others.

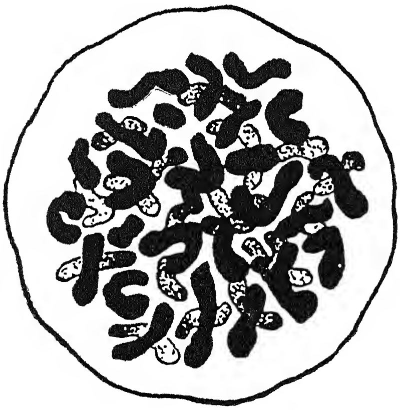
Since the father and the mother each provide one chromosome for each of the twenty-four different chromosome pairs in the human cell, there must be two of every kind of gene, one inherited from the mother and one from the father. But the two genes of any single pair need not be exactly alike. A gene that promotes normal blood clotting, for example, may be paired with one, derived from the other parent, that is unable to provide normally clotting blood. When the two genes in a pair are different, one is usually more potent than the other and dominates. If a person has one gene for normal blood clotting and one that is ineffective, his blood will clot normally. It will not do so if both genes of this particular pair are ineffective.

Genes and chromosomes, then, are present in the fertilized egg from the very beginning and they control development all through life. Some produce their effects early, others only in later years. Thus diabetes commonly shows up after the age of forty; the genes that make a long life possible may not reveal their presence until even later.

The genes represent the potentialities of all growth and development. Yet since no human being can develop in a vacuum, normal growth and development can take place only in a normal environment. There must be an adequate supply of many sorts of essential things — water, mineral elements, fats, sugars and starches, proteins, vitamins, oxygen and so on. There must be adequate elimination of waste substances of all kinds. There must be careful control and regulation of physical and chemical conditions, such as temperature, acidity and the concentrations of substances. Changes in any of these factors may, and indeed will, alter the processes of growth and development in such a way that even some inherited characteristics will turn out differently.

When we speak of an inherited characteristic, then, we generally have in mind one that is not readily altered by ordinary changes in the environment, or that we do not yet know how to change — such as eye color, for instance. However, this does not mean that the characteristic cannot be changed at all or that we ought to be fatalistic about such things. For example, diabetes, which in former times was a fatal disease, is inherited — that is, there is a

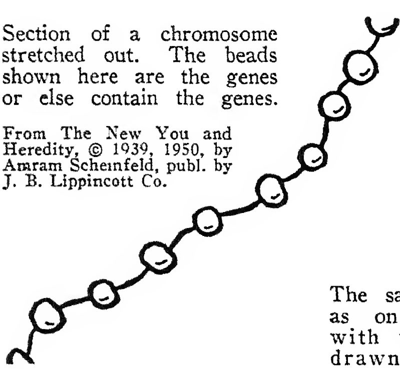
gene responsible for it. Yet injections of insulin will keep it under control; in fact, some day we may even learn how to prevent it from developing at all. So an inherited condition may well be cured or pre-



Human chromosomes under the microscope; they carry the thousands of genes that represent the potentialities of all our growth and development.

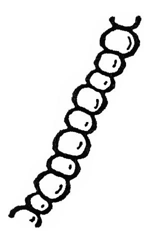
vented. In that case, we must remember that the responsible gene has not been eliminated by our treatment, and that therefore the work of coping with it will have to be done all over again in the next generation.

The environment of the still unborn baby is highly regulated and very uniform compared to its surroundings after birth.



Section of a chromosome stretched out. The beads shown here are the genes or else contain the genes.

From The New You and Heredity, © 1939, 1950, by Amram Scheinfeld, publ. by J. B. Lippincott Co.



The same section as on the left, with the genes drawn together.

How the entire chromosome looks under the microscope after it has been greatly compressed and dyed.

Hence the features of growth before birth are much the same for everybody, except for those differences that result from different genes. After birth, however, more and more differences come about in persons because of their different surroundings, food, care, training and so on. So, although all a person's potentialities depend upon the genes he has at birth, what will come of these potentialities depends more and more on his special environment as he grows up. Nature and nurture both matter.

The growing process in the human body

In its simplest sense, growing means adding living matter to the matter that is already present in the body. Every person is made up of a vast number of tiny cells. Because there seems to be a limit to the size that a single cell can have, a body's growth comes about through the multiplication of the number of cells. Each cell divides into two, and then these grow to their full size and divide in their turn. It takes over forty successive divisions of the cells to produce a baby from a fertilized egg. By that time the growing process is almost finished, at least by comparison with what has gone before. The weight of the human body, from fertilized egg to newborn babe, has multiplied 2,500,000,000 times; it increases only twenty times or so from newborn babe to adult.

Both brain and voluntary muscle have their full quota of cells before birth, and no new ones are produced after that time, even to replace those that happen to die. In most organs, such as the liver, for example, cells practically stop dividing by the time of birth, although they can begin again to do so if a part of the organ has been destroyed. In only a few structures that are short-lived or exposed to destruction from wear, injury or attack by germs are the cells constantly multiplying in number. The skin is one of these, the blood cells another. Red blood corpuscles, for example, can serve as carriers of oxygen for only about eighteen weeks before they break down. There are

such enormous numbers of them that, in the bone marrow where they are produced, some two million new ones must be turned out every second of the day and night.

The two main stages of growth and development

There are two main stages of growth and development. First, there is an automatic period. This is followed by a functional stage during which development depends upon contact, strain and stress, exercise and learning and all sorts of experiences. Birth does not constitute a dividing line between these two stages. Many automatic steps in development occur after birth, such as the change from blue to brown eye color in many persons during childhood, or the regular changes of adolescence in everybody. On the other hand, many functional steps in development are taken before birth. When the unborn baby kicks and turns within its mother's body, it is beginning to make its bones and muscles strong through use.

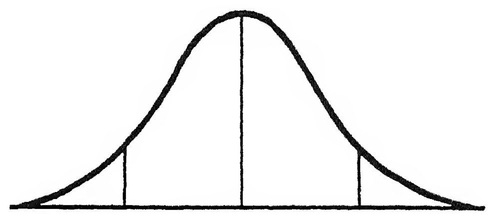
Because some people are well fed and some are half-starved, because some stay well and others get sick, because of all sorts of other circumstances there must inevitably be differences in people's growth and development. These will be heightened by differences in the genes they inherit, for no two people, except for identical twins, have all their genes alike. So some people tend to grow faster, others slower, some fatter, others leaner, some taller, others shorter.

The significance of words like "average" and "normal"

In view of these natural differences between individuals, we should be cautious about using such words as "average" and "normal" and "standard." They are helpful at times, but they are not to be taken too seriously.

Let us consider, as an example, the tables of standard weights that are to be found on practically every set of platform scales. The weight of the body changes with age, naturally, and it varies with sex; so separate tables have been made for males and females, grouping each according to age. The figures in the tables are average figures for a great many persons of the same age and sex.

Only a few persons in such a group will be of exactly the average weight. The others will be distributed on either side of it, in a pattern known as a "normal frequency distribution." In graph form this relationship looks like this:



Most members of the group will cluster rather closely around the average.

But it is perfectly normal — in fact, quite to be expected — for some to depart a good deal from the average. It is all very well to know what the average is, but it is just as important to know how much variation is characteristic of the group to which the individual belongs.

When we say that a person is "abnormal," we imply that he is very unusual for that group to which he properly belongs, or that he is a member of a group which is very unusual compared to the rest of the population. Just how unusual is "very unusual"? That is entirely a matter of personal judgment. Most scientists are inclined to rate as very unusual any exception that occurs less than one per cent of the time. However that may be, it is better to appreciate human differences and to make allowances for them than to try to squeeze everybody into the common mold of the "average," or "normal" or "standard."

Growth in infancy and in early childhood

Look well at this tiny bundle of reflexes, just come into the outer world to grow and develop into a man or a woman: from five to eleven and one-half pounds of helplessness, destined to become skillful in move-

Ewing Galloway, N Y

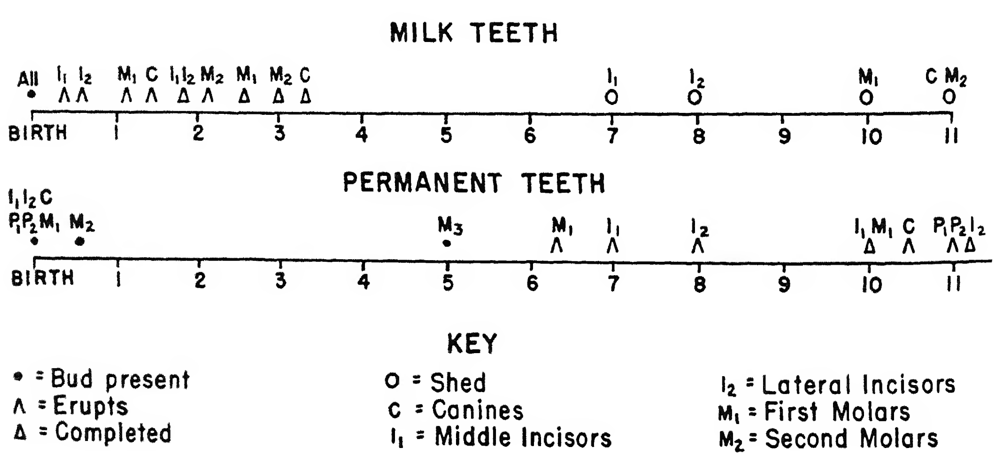
A case of unusual development the famous dwarf General Tom Thumb, who stood 2 feet, 1 inch high.

ment and to learn to think. Nothing is more marvelous than the story of its growth.

The very first adjustment after birth has to be that of breathing, for the supply of oxygen from the mother has been cut off for some little while, and death will come quickly if the breathing is not started. For several weeks the breathing muscles of the chest, abdomen and diaphragm have been practicing a bit at inflating the lungs. The shock of the cold outer air as the baby emerges from the mother's body usually provokes a cry that draws air into the lungs. Breathing then starts. For the first year breathing depends mostly on the abdominal muscles, and it is shallow and rather rapid. After the baby commences to sit up, the thoracic, or chest, muscles begin to assist with the breathing, and it grows deeper and slower. Between three and seven years of age the adult pattern of breathing is established.

The smaller a body, the more surface it has in proportion to its bulk. Since greater surface means more loss of heat, a baby, pound for pound, loses more heat than a grownup. That means more food and lots of muscular activity — mostly kicking and squirming — are needed to produce the heat Because of high heat loss and poorer control over heat production and body temperature, babies have to be protected against chills.

Body temperature is not well regulated until a child is about two years old, although in this respect each child is apt to follow his own rules. Temperature controls are connected with the development of the thyroid gland, which normally shows a steady rate of growth from birth to maturity. If a

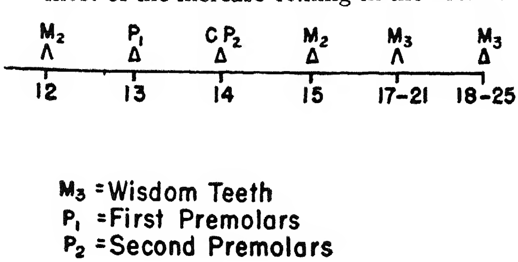


This chart shows the chief events in the development of the milk teeth and the permanent teeth, the key that is given below indicates the meaning of the symbols that are employed. Note that the events re-

thyroid is underactive from birth, a child soon becomes a cretin. Growth is stunted to dwarf size; a puffy fullness of face, lips, nose, tongue and the skin in general is produced. The intelligence fails to develop normally and the child becomes practically an imbecile. Fortunately, if thyroid feeding is started soon enough, it can overcome this condition.

The development of the digestive system is another necessity in infancy. Everybody knows that a small baby cannot eat adult foods, although its digestive organs are further advanced than most of us realize. The salivary glands increase in weight about five times in the first two years, but they are ready to secrete at birth, and by the end of the first year the saliva has a concentration of the starch-digesting enzyme equal to that of adults. The stomach increases its capacity ten to twenty times in the first two years, and more later. A little baby's stomach can hold only a few ounces, so that it must be fed more often than older children. The gastric and intestinal glands and the pancreas are all ready for action at birth, although their secretion is small in amount and the pancreas is only a little more than 4 per cent of its adult weight. At three years it has already completed one-third of its growth.

The liver is relatively large at birth, and although its weight increases about ten times in all, the ratio of its size to that of the whole body diminishes by half. Its early growth indicates how important it is to the infant for storage purposes and for the formation of bile. Both the large and the small intestines just about double in length between birth and full growth, with most of the increase coming in the first two years. At birth the inner layer of the intestines is well developed, so that digestion and absorption are well advanced. But the muscular layers are still thin and weak and have a lot of growing to do.



corded in the chart overlap; thus, the first molars erupt before any of the milk teeth are shed.

The development of the milk teeth

It was once thought harmful to give a baby solid food before it was a year old, but now the general practice is to begin feeding solid food between three and six months of age. This solid food must be soft and well mashed until the baby can chew for itself At birth, the milk teeth and most of the permanent teeth are already present in the gums, but eruption of the milk teeth does not begin until the sixth or seventh month, as a rule. Then the middle incisors start to come in, closely followed by the lateral incisors. The lower teeth break through the surface of the gums before the upper ones. The first molars erupt at 12 to 16 months, the canines afterward (16 to 20 months) and the second molars last of the milk teeth (20 to 30 months). The buds of the permanent teeth already present at birth include all those that replace the milk teeth and the first permanent molars besides. The chart on pages 3060-61 shows how the chief events in the development of the two sets of teeth overlap.

The circulatory system makes a considerable adjustment

The circulatory system has to make a considerable adjustment both at the time of birth and afterward. The lungs receive very little blood before birth, but afterward the whole flow must be passed through them. This is brought about by the closing of the passage between the right and the left auricles of the heart; thereafter all the blood entering on the right side of the heart is pumped to the lungs.

At first the baby's blood pressure is low and its heart beat about twice as fast as that of an adult. The blood pressure slowly rises. The heart beat becomes slower, losing about 25 beats per minute in the first two years, another 10 by the age of five, and gradually reaching the final rate of

about 70 per minute. The heart, like the liver, is relatively large at birth. While it doubles in the first two years and triples in size in four years, it does not keep pace with the growth of the rest of the body

The kidneys are also relatively oversized at birth and quite able to handle the task of excreting the body's wastes. Between birth and one year they triple in weight and by that time they have already attained one-fourth of their full size.

The transformation of cartilage into bone

The skeleton and the voluntary muscles of the body have far more of their growth ahead of them than the heart, liver and kidneys, which are relatively oversized in infancy. The bones of the newborn baby are hardly bones at all. Most of the skeleton is still formed of cartilage, which is softer than bone. Centers of transformation into bone, about eight hundred of them, arise in the cartilages before birth in some cases but in most cases after birth.

In the long bones of the arms, legs, hands, fingers, feet and toes the earliest center of bone formation in each bone is in the shaft. Not long after birth secondary centers arise in each enlarged end of the bigger arm and leg bones; these secondary centers are known as epiphyses. The cartilage between the epiphyses and the main center in the shaft grows rapidly enough to keep up with the transformation of cartilage into bone on either side of it. This keeps the epiphyses from becoming rigidly fixed to the lengthening shaft; instead, they are pushed farther and farther apart. Only after the bone has reached its full length, toward the end of adolescence, does the cartilage stop growing, allowing the epiphyses to become firmly attached to the shaft.

The age of a child's skeleton can easily be told from X-ray pictures. For instance, at birth there are no epiphyses in the hand and no bones at all in the wrist, only cartilages. At one year, two centers of ossification (formation into bone) have appeared in the wrist and a number of epiphyses have developed in the hand. Between three and five years of age, all the epiphyses in hands and fingers arise, together with two more centers in each wrist. By five, only one center is still lacking. Girls develop the skeleton more rapidly than boys, though they lag behind in stature and weight in these early years.

The fine inner structure of the bones undergoes a steady process of reconstruction during growth. Bone-destroying cells are constantly at work eating away the bone already made and allowing the bone-forming cells to replace it. The new patterns of the bone fibers and plates are so arranged as to give the bone maximum strength in resisting strains and stresses, which change in direction as the child grows and alters its posture and its muscular activities.

The skull increases in size rapidly during babyhood

On every little baby's head are soft places where the bones of the skull are still incomplete and soft cartilage covers the brain. During babyhood the skull increases in size very rapidly, the cranium, or brain case, doubling in capacity in the first year. The soft spots soon disappear as the cartilage is converted into bone; even the biggest one has closed by the time the baby is a year or a year and a half old. The cranium reaches its full size by six years of age. Meanwhile the bones that form the face grow quite slowly; their growth becomes rapid only as the teens are reached. That is one reason why young children's faces are so different from those of adults.

The rest of the skeleton passes through similar changes. At birth the spinal column is largely cartilaginous, but the ribs, needed at once for breathing, are already partly ossified. The typical curves of the spine develop after the baby begins to sit up and to stand. Just as the face and cranium grow at different rates in different periods, so other parts change in proportion, too, because of differences in their rates of growth. The arms and the legs both become longer in relation to the trunk.

The voluntary muscles of the body have the most growing to do. Yet up to four years of age they merely keep pace with the rest of the body, making up one-fourth of

the weight. Then they begin to grow rapidly, making up about three-quarters of the entire gain in weight. Since no new fibers are added, this growth is largely due to an increase in the size of the single fibers.

At the start, the eye muscles and those needed for breathing are best developed, and the arm muscles are further along than those of the legs. The ligaments and tendons that attach the muscles to the bones are still poorly developed at birth; the connective tissues lack elastic fibers. It takes constant use to strengthen the muscles and their attachments and to bring about co-ordination between different muscles. But use is not enough; it must be supplemented by the development of the senses and the nervous system and by the acquisition of learning habits.

When a baby is ushered into the brightness, noise and cold air of its new world, it is alarmed and confused. The sense of warmth and security that it develops as it snuggles against the mother and satisfies its hunger at her breast is the first great experience of life. Many who have studied the human mind and emotions think that the shock of birth and the sense of security, or the lack of security in earliest babyhood lay the foundations for the whole development of the personality.

The development of the nervous system

The nervous system is far advanced physically at birth. The brain is already one-fourth full grown, although the whole body is only one-twentieth of its mature weight. In two years the brain attains over half its full size, and at nine it has practically finished growing. The inner structure of the brain is also almost complete at birth, and no new cells are added to it thereafter. But the nervous system is very immature; perceptions, habits, learning processes and memory are still to be established. Some reflexes, such as yawning, coughing, sneezing, sucking and swallowing, are present at birth or very soon thereafter, but other reflexes have yet to appear. Hearing and the touch sense of the lips and tongue are well developed. It takes two or three months, however, before the baby can focus its eyes properly and see at all clearly. During this period the baby is wrapped up in itself; it is particularly interested in the state of its stomach.

The co-ordination and control of bodily movements

The big job of the first year is to learn to co-ordinate and control bodily movements. First comes turning the head, and learning to focus the eyes and to co-ordinate them in following a moving object. After about two months comes the first smile — for in emotional development evidences of displeasure and discomfort precede signs of pleasure and sociability. Next comes the co-ordination of hand and eye in grasping an object and transferring it from one hand to the other, in reaching out for it and in exploring it by turning it over and popping it into the mouth.

The cooing welcome that the baby gives strangers at three months of age is likely to be replaced by distrust and alarm at six months, for it can now distinguish between friends and strangers. Rolling over and sitting up comes in the second half year; creeping soon follows. Moving about while standing up and holding on and finally standing alone are the big achievements made toward the end of the first year or early in the second. Meanwhile a lot of experimenting in making sounds has been going on, and sounds that mean something — at least to the baby — may be used by the end of the first year.

In the second year there is a widening understanding of self and of home relationships. Discipline comes to have significance as the baby learns to understand what "No" means. The one-year-old soon learns to assert himself, too, by saying "No." Control over the body functions of elimination should improve rapidly at this age, although the bladder is still so small that urination must be frequent. The baby is eager to explore everything, but distraction is frequent and easy. Between one and three years, the baby learns to focus his interest and attention on things, just as he had learned earlier to focus his vision. He

becomes more sociable and dependent on the company of others, while at the same time he is learning in other ways to be more independent. Suspicion of strangers is likely to reach new heights, and worries and fears begin to enter his mind. He is learning fast, progressing from toddling to walking, from babbling gibberish to speaking sentences, from exploring his house to exploring the neighborhood. He learns to feed himself; he experiments with temper tantrums; new emotions, such as jealousy, appear.

From three to six a new world opens up. Most of the contrariness of the baby just becoming aware of its own individuality now tends to disappear. Curiosity about all sorts of things is a dominant characteristic; this is the great age for questions. Keenness of observation increases steadily at this period, as is shown by the skill with which the child can work out simple jigsaw puzzles. Imagination reaches a peak, too. This is the age of make-believe, of imaginary playmates and fairy godfathers who may be as real to the child as his parents. Imitation becomes very prominent; a great deal of experience is gathered through imitating grownups. Playmates become an important part of life.

The school child — from six to eleven

In this period physical growth, rapid at first, slows down and nearly comes to a standstill. The child becomes less dependent on his parents and develops a sense of co-operation and self-control. He begins to learn by thinking things out instead of purely by imitation.

School begins the formal education, and soon parents find that teachers have largely supplanted them as fountainheads of knowledge. Independence is expressed in bad manners and occasionally rebellion against parents' authority. Other children now set the pattern that Johnny and Mary strive to follow. Gangs and clubs spring up as the children unconsciously strive to get their own community life organized. At this age conscience develops into a profound emotional guide. There will be sudden onsets of good behavior in the usually heedless child, and attempts at neatness in the usually disorderly child. Compulsions are common; the child feels for example that he must not step on the cracks in the sidewalk or that he must touch every third picket in a fence.

Understanding and intelligence develop apace. Learning now becomes conscious; children begin to *try* to learn instead of learning without being aware of the fact. Skills, motor and verbal, advance rapidly with practice. Improvement in the precision of hand movements increases much more in these five years than in the five to follow, although speed in making hand movements will continue to increase at the same rate. In these years, too, the child develops new reading skills. He cuts down the number and duration of the pauses and backward movements that the eyes make as they move along the lines of the page.

The critical period of puberty and adolescence

Puberty is a time of rapid growth, bringing about sexual maturity; adolescence occupies the rest of the period of maturation. The growth in this period, from the age of eleven to nineteen (in girls) or twenty-one (in boys), depends in particular on increased hormone secretion by the pituitary and adrenal glands and sex organs. Sex hormones stimulate the rapid growth to mature size of the internal and external sexual organs, which have grown very little since infancy.

The very rapid increase in height at this age is due mainly to the lengthening of the legs; the trunk grows chiefly in girth. Breathing capacity increases; the liver, heart and large blood vessels double in size; the blood pressure is stepped up. These changes make possible the effective use of the muscles, which also just about double in size, at least in boys, in this period. Physical strength increases rapidly; lack of perfect co-ordination brings about temporary awkwardness. While the cranium changes very little, the bones of the face lengthen considerably. The pores of the skin enlarge; its oily secretion increases and

there may be some trouble with pimples. Childhood's visage fades away and the features of the adult emerge.

Puberty arrives about two years sooner in girls than in boys. It now comes, on the average, a year earlier than it used to a generation or two ago, perhaps because of better general health and nutrition. The puberty of the girl usually begins at eleven

years of age. She then shoots up three inches or so in a year, changing from a plump little girl to a slender young maiden almost overnight. The gain of ten to twenty pounds per year in weight all seems to go into height. The first outward sign of sexual maturation, the enlargement of the breasts, is accompanied by an enlargement of the pelvis that throws the hips farther out and makes the thighs slope inwards from the hips to the knees. There is a parallel but slighter change at the shoulders.

Hair appears on the pubic regions and, usually somewhat later, in the armpits. At thirteen, on the average, the young girl has her first menstrual period, marking the first release from the ovaries of a mature egg cell. She may gain in height for the next few years, an inch and a half the first year, perhaps three-quarters of an inch the next and still less thereafter; but her growth is rapidly slowing down. By the age of fifteen, the adolescent girl is about as tall as she ever will be.

Some girls enter puberty at eight or nine years of age and others only when they are thirteen or fourteen. These variations in

Both photos, Lambert, from Lewis

The pictures show the same young lady as a baby and as an adult. Note that the baby's cranium has developed more rapidly than the bones of the face

development may lead to considerable self-consciousness and even alarm on the part of the child. She should be reassured, however, for there is no physical ill consequence from either precocity or delayed sexual maturation.

For the boy, puberty sets in, on the average, at thirteen. He gains rapidly in height and strength as his shoulders broaden and his muscles fill out. As his reproductive organs mature in size, the formation of the spermatozoa and of the sexual glandular secretions begins. The pubic hair appears early, the hair in the armpits and the beard somewhat later. The larynx enlarges; the vocal cords lengthen considerably; the voice breaks and after a time it becomes about an octave deeper. At fifteen, two years after the onset of puberty, the boy's growth begins to slow down abruptly. He too will gain another two or three inches, but more and more slowly. By seventeen most boys are full-grown in stature, although still likely to be rather spare and awkward.

During puberty and adolescence, psychological development is not less pronounced than physical development. The sex hormones work a revolution in the attitudes of young girls and boys. Made self-conscious by the changes taking place in herself, the young girl tends to exaggerated her worries, perhaps to think that she is different and abnormal. She is likely to be sensitive to criticism. Sometimes she wishes to be

considered as a grownup; sometimes she seeks the protection she enjoyed as a child. As boys of her own age outstrip her more and more in athletic activities, she tends to develop more interests of a passive nature. She is apt to become romantically attached to some older person, developing a "crush." The young lad who is maturing is also self-conscious, troubled and given to romantic daydreams; but his psychological problems are usually less severe than those of a girl his own age.

The gulf between boys and girls of the same age

Because girls mature two years before boys, a sharp social gulf is created between girls and boys of the same age. In a given class at school the average girl towers above the average boy and begins to be grown-up and romantic in her ideas and interests, while "he is still an uncivilized little boy who thinks it would be shameful to pay attention to her" (Spock). It is best to allow for this situation in planning social affairs for youngsters by grouping young girls with boys a couple of years older. Individual children ahead of or behind the usual schedule of development also ought to be thrown with those of their own developmental age rather than with those of their chronological age.

Intelligence continues to develop rapidly in these years. The span and speed of visual perception, on which so much depends in learning, reach their peak at sixteen or seventeen years of age; so does memory; so do speed and accuracy in motor skills and habits. In fact, general intelligence, which shows a steady increase through childhood and early adolescence, improves little or not at all after the age of eighteen. The peak of mental development, at least in the simpler, more measurable qualities, is therefore reached even before the physical prime of the individual has been attained.

The period of maturity and aging

The human body does not remain at the peak of its powers for very long. A slow but steady decline is the general rule for the years after maximum efficiency is attained. Aging is a normal, not an abnormal process; it cannot be said to begin at any one time. Because the peak of development comes at different ages for different parts of the body, there is no one age of highest efficiency in every respect.

Examples of different peaks of development

For example, the ability of the lens of the eye to change its shape so as to focus on near-by objects declines steadily from birth up to the age of fifty, after which it remains the same. The thymus gland and other lymphoid tissues reach their maximum size at ten to twelve years of age, and then rapidly diminish in size, so that at the age of twenty they have only half the weight they possessed at their largest. They are actually degenerating while the reproductive organs and the voluntary muscles are doing their most active growing.

Muscular strength is greatest in the middle and late twenties, and an athlete is "old" at thirty. The muscles of the back relapse to the level of their power at twenty during the thirties; the biceps reaches the same level in the forties, the hand grip in the fifties. The biceps and back muscles of the average man of sixty-five are only slightly more powerful than those of a woman twenty-five years of age.

Changes in bone structure in adulthood

The bones, too, undergo progressive changes. The bones of the skull, between the ages of twenty-five and thirty, make rapid advances toward complete fusion. Later in life the bones lose mineral matter and acquire more fibrous organic matter in its place. They become more brittle; their power to regenerate and knit after a break is gradually impaired. But these changes are slow. Only after seventy does the atrophy of the jaws produce a marked change in the face, particularly after the teeth become loose in their sockets and fall out.

The regulation of stable bodily conditions, such as body temperature, concentra-

tion of blood sugar, and balance between acids and bases becomes more difficult with the years. The colloids of the protoplasm lose their capacity to take up water; they become less stable and less reactive as they shrink. The healing of wounds is slower and takes longer; at the age of fifty they heal only half as fast as at twenty. All this is simply another way of saying that age is not as resilient as youth.

The digestive organs can hardly be said to show the effects of aging at all, except in an increasing liability to such disorders as gastric ulcers, pernicious anemia, cancer and the formation of gallstones. Nor do the lungs appear to alter much with advancing age, except in elasticity.

The loss of elastic tissue in the skin

There is a loss of elastic tissue in the skin, which becomes thinner as the fat stored just beneath it is withdrawn. Folds and wrinkles appear. The hair becomes gray and sometimes falls out. The nails, especially the toenails, tend to thicken and become deformed as their rate of growth slows down.

The reproductive organs have a rather definite span of activity. In women, menopause, which comes at thirty-eight to fifty years of age, brings a full cessation of the capacity to bear children. Like puberty, this change is brought about by the hormones, most probably those of the pituitary and adrenal glands. In men, the prostate gland declines steadily from the age of forty on, and is old at sixty; but the testes may continue to produce sperm indefinitely. Over-all sexual capacity, however, probably declines from early maturity on.

The heart and blood vessels are most important in the matter of aging because they are usually first to succumb. "A man is as old as his arteries." Breakdown of the circulatory system causes only 14 per cent of the deaths between the ages of twenty and thirty-nine, but it is responsible for almost two-thirds of all deaths after the age of sixty. Deposits of calcium in the heart and arteries, loss of elastic tissue, high blood pressure, heart strain, burst capillaries, blood clots, failure of circulation — these are the common steps in the process. Perhaps the brain and nervous system and the kidneys would hold out indefinitely if it were not for the failure of their elaborate circulations.

There is a steady decrease in the number of taste buds as one grows older, and the sense of smell also declines. Hearing above high C is impaired but below that it hardly changes at all, except in the really deaf. The eye, except for the loss of focusing power in the lens and a decline in the sharpness of marginal vision, is good for 125 years, according to those who should know. In the brain and spinal cord, the white matter suffers more than the gray, and the frontal regions of the brain more than the more primitive parts.

The outstanding thing about aging is the tremendous variation between individuals in its rapidity and its particular course. Even in the same individual, many of the processes involved in aging appear to be quite independent of one another: the nervous system, the respiratory system and the circulatory system may break down at different periods. Long life runs in certain families. The genes undoubtedly play a big part in the later years, just as they do before birth and in infancy, childhood and adolescence.

The decline in ability in learning activities

In almost all learning activities there is a slow decline in ability after the age of twenty, just as there is in physical skills and capacities. But if the factor of speed is eliminated from intelligence tests, older persons do just about as well in them as younger ones, with one important difference. Older persons can learn anything that fits the established pattern and habits of their minds just as well as younger persons can, but they find anything entirely strange — especially anything that upsets their established habits — far more difficult.

It is a remarkable fact that in particular skills or capacities many persons over sixty, and even some over eighty, actually surpass the average persons of their own sex in the

very prime of life. The slow decline in learning capacity as we grow older, for instance, really means little when we consider that one person may at sixty or seventy still learn twice as rapidly as someone else who is twenty. Old age must be more moderate, but it can also be rich and fruitful. That is why we should plan in our younger years those interests and activities that will keep us young at ninety. For when our interest in life is gone and only resignation is left, there will be little to keep us here.

Death — ringing down the curtain on the drama of life

Death represents the breakdown of the vast chemical and physical complexity that exists in every living thing; it marks the end of the ceaseless interchange of substance between the living organism and its surroundings; it brings to a close the perpetual expenditure of energy that is characteristic of life. It means the inevitable victory of the disruptive forces of nature over the efforts of the individual living thing to grow, to develop according to its own laws and to reproduce others like itself.

Death is really gradual, not sudden. It is true that once a vital system has failed or an overwhelming shock has been experienced, in a few moments the damage done is irreparable. Yet certain tissues may remain alive for a considerable period thereafter. For example, for a number of hours after the death of a person, the still-living cornea of his eyes can be used to make windows in the opaque corneas of certain blind people.

Until our prime, disease and accident are the great enemies of long life. Thereafter we are confronted particularly with the gradual wearing out of the bodily mechanism.

From the days when Louis Pasteur and Robert Koch showed that many diseases are due to bacteria, tremendous strides have been made in curing and preventing communicable diseases. Call the roll of those whose names once aroused the utmost terror: typhoid fever, cholera, typhus, plague, smallpox, diphtheria, yellow fever, tuberculosis; they are now conquered, or nearly so. Nutritional deficiencies have been unmasked and dealt with; scurvy, beriberi and pellagra need no longer be feared. Serums and vaccines and new drugs almost miraculous in their effects have played their part in this supreme achievement of human science. This story is told elsewhere in The Book of Popular Science.

In place of disease, fatal accidents are rapidly coming to be the chief cause of death among those under forty. Automobile accidents alone now kill nearly twice as many as die of appendicitis. One thing is quite clear about accidents — they are not entirely accidental. Perhaps the greatest factor in causing them is the individual character of the persons directly involved. A great deal of investigation remains to be done to find out the reason for the undoubted fact that accidents happen much more often to certain people than to others.

The diseases that menace those past the age of forty

Functional diseases kill older people — diseases of the heart and blood vessels; kidney ailments; cancer. Very little progress has been made in checking the effects of these diseases; they represent problems that coming generations will have to solve. Cancer, in particular, because of the horrible suffering it causes and because of its strange, unsolved relation to growth, represents a standing challenge to men of science.

Perhaps in another century these ills, too, will be vanquished, and the average baby will then look forward to living out the full term of the hereditary life span of the human species. Nobody really knows how long this life span really is. The Russian scientist A. A. Bogomolets asserted that the average man should live to be 150, but he may have been unduly optimistic. The age of 80 may well become the average life span; we may possibly advance it somewhat beyond that mark.

Yet in the end we must all die, and others will carry on. Perhaps new minds, new hands, new eyes will develop more effectively than we the potentialities that lie in the ultramicroscopic genes, and so may shape a better world in days to come.

THE STRANGE WORLD OF "SILENT" SOUND

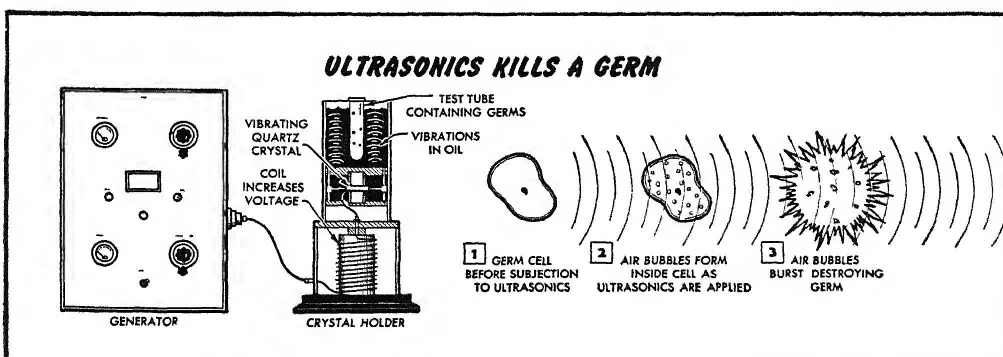
Ultrasonics, a New Tool for Man

by
HELEN MERRICK

AS you walk down a country lane at the height of summer, there is a drowsy murmur of humming bees, droning flies, chirping crickets. Yet even as you hear these faint, thin noises, the busy insects are making other sounds that no human ears can ever catch unaided. Nonetheless, scientists have invented devices both for detecting such "silent" sounds and for producing them. The study of these sounds is called "ultrasonics" (from "ultra," meaning "beyond," and "sonic," meaning "sound"). Occasionally such sounds are referred to as "supersonic," but nowadays this word is used more often to describe speeds exceeding that of sound in the air — about one mile every five seconds. Thus we speak of supersonic planes and of supersonic wind tunnels, in which research on such planes is carried out.

Since ultrasonic sounds are different from sounds that we can hear in only one respect, let us see first what any kind of sound is. For a sound to be created, three things must happen. First, an object must be made to vibrate, as when you press on an automobile horn, pluck a taut string or strike a tuning fork. The rapidity of the vibration — in more scientific terms, the frequency of the sound — depends on how elastic and dense the substance of the object is. No matter whether it is struck hard or lightly, the rate of the vibration for that substance will be the same and is its natural frequency. The frequency gives sound its pitch — its high or low tone. The more rapid the vibration, the higher the pitch.

Second, as the object moves rapidly to and fro, it alternately pushes and pulls at the near-by molecules of whatever medium surrounds it, usually the air. (Sound cannot be created in a vacuum; there must always be some medium — a gas, a liquid or a solid.) When the molecules are



Courtesy, Popular Mechanics Magazine

Sound waves of tremendously high frequency literally shake germs to pieces. The first shock of the waves makes air bubbles form (2) in a germ. As the waves continue, the bubbles burst (3) and shatter it.

pushed together, they are compressed; when they are pulled, they are spread apart, or rarefied. Sound travels because this double motion is communicated to the molecules of the medium ever farther and farther away from the source of the sound. Thus a sound wave is a series of compressions and rarefactions in the medium through which it passes. Throughout the course of a sound wave's journey and regardless of its speed, the frequency of the sound remains the same as that of its source. The wave of motion might be compared to what happens when one pushes the last man of a long line of people waiting for a bus. The last man will have to push on the one in front of him and so on down the line. The initial push thus moves forward from the last man, "carried" by the people in front of him. The push travels along, but the line does not move.

Third, the sound waves must be received by some organ, such as the ear, or by some mechanical device. It is like the completion of a call when your friend answers the telephone. (Biologically speaking, sound is the translation in the brain of sensations received through the nerves of hearing.)

The difference between ultrasonic and ordinary sound waves is a matter of frequency. In fact, it is necessary to make this distinction only because human hearing has certain definite limits. The human ear is so constructed that even at its keenest it can register as sound only those frequencies that lie between 20 and 20,000 times, or cycles, a second. Any frequencies below 20 or above 20,000 are silent as far as man is concerned. Ultrasonics therefore is concerned chiefly with the frequencies above 20,000. Some study has been made of the lower range, but the upper one is by far the more important and interesting.

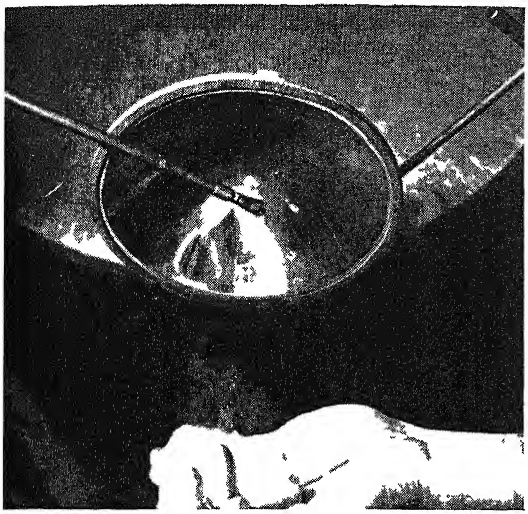
It must be remembered throughout this article that while there are certain similarities between the way electromagnetic waves (light, radio waves and so on) and sound waves behave, electromagnetic waves travel through space and sound waves can travel only through matter. Also, electromagnetic waves travel much faster, at about 186,000 miles per second.

To return to the insects, it is thought that some of them probably communicate with each other by means of "silent" sound — silent to us, that is. Certain grasshoppers produce sounds with a frequency of 40,000 cycles a second. Small mammals, such as cats, guinea pigs and rats, can hear frequencies up to 30,000 cycles and maybe even higher. Perhaps if you have a dog, you own a "silent" dog whistle. Its tone is pitched so high that you cannot hear it; but your dog, with a wider range of hearing than a human being, responds to the whistle.

Perhaps no members of the animal kingdom are so dependent on ultrasonic waves as bats. Experiments have proved that their inner ears are so delicately made that they can hear frequencies as high as 100,000 cycles. This was discovered in solving a problem that had long teased zoologists: What makes it possible for bats, nocturnal animals that fly about in the dark hours of the night, to avoid obstacles?

Westinghouse

Making ultrasonic waves "visible." To make the pictures (the room is then darkened), a photographic plate is placed between the vibrating oil, in the jar, and an intense light. Time exposures of up to one minute then register the waves.



General Electric

Fire from a whistle! "Silent" sound waves from a small whistle are focused downward to a point of high intensity. The waves agitate the cotton particles so much that a tiny fire starts by friction.

After an apparatus was developed by which any high-frequency sounds the bats made could be detected, a number of the furry creatures were masked and made to fly through a room in which wires hung from the ceiling, only a foot apart. Provided the wires were not extremely thin, the masked bats avoided them with no trouble at all. The apparatus revealed that as a bat flies about, it produces ultrasonic cries, which are echoed back from any object in its path. As a bat approaches some hindrance, it may give as many as thirty to fifty of these cries per second; but if the path is clear, the cries are uttered at a lower rate.

As proof that these echoes guide the bats, they blundered helplessly into the wires and even into the walls of the room when, in addition to being masked, their ears were stopped or their mouths were gagged.

Later experiments showed that each cry consists of about 100 individual sound waves, which crowd together as each cry begins and then spread farther apart toward the end. The frequency of the waves ranges from 100,000, or even higher, at the beginning, down to 40,000 or even lower. It is likely that the longer intervals between vibrations at the end of the cry are to help the bat hear the echoes from the first part. (This is really a kind of natural frequency modulation.)

However, you may well ask why the bat's cries need to be of such high frequency for the animal's purpose. The answer helps to explain one of the uses of ultrasonics to man, and has to do with the wave lengths of sounds.

We have said that a sound wave is a series of compressions and rarefactions The wave *length* of a sound is the distance from one compression to the next. Consequently, the higher the frequency of the sound, the shorter its wave length must be. When the wave length is comparatively long, the sound flows around small obstacles, much as a large wave in the ocean surf flows around a piling, with hardly any disturbance, or reflection. (This ability of any kind of long wave — light and other electromagnetic waves as well as sound — to spread around an object is called diffraction.) But with short wave lengths, the sound is reflected back, or echoed, from small objects, just as little wavelets would be tossed back from the piling. In other words, short wave lengths are diffracted less. This is why the high-frequency cries of bats echo back from objects as small as wires, provided they are not hair-thin, and the animals are safely guided around unseen obstacles.

As long ago as World War I, a French scientist, Professor Paul Langevin, found a way to make use of this echoing quality of ultrasonic waves. At the naval base of Toulon, on the Mediterranean Sea, he and his assistants built an apparatus that could send strong bursts of high-frequency sound through the water. The waves traveled in straight paths without being diffracted. When they hit a submerged rock or a submarine, an echo returned. Here was a new way of detecting underwater perils.

After the war, two Canadian scientists applied Professor Langevin's discoveries further. They worked out a device for locating treacherous icebergs and hidden reefs.

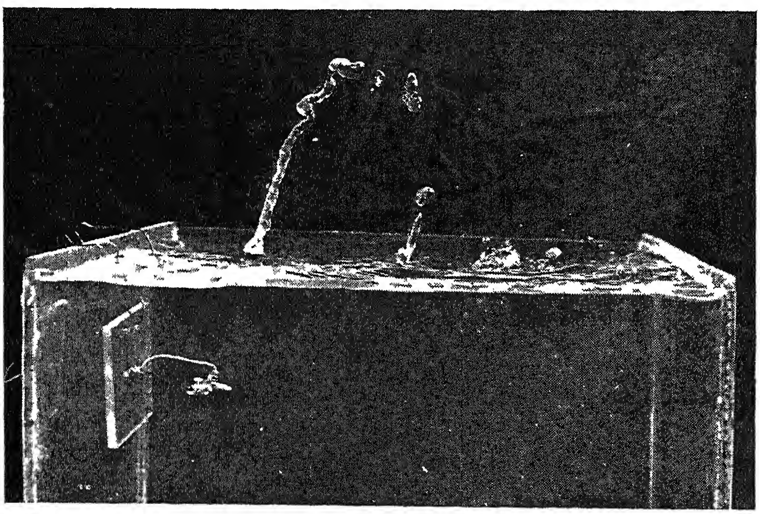
Sonar, developed during World War II,

was a still greater refinement on the early ultrasonic underwater devices. In fact, sonar had a great deal to do with the conquest of the dread "wolf packs" of German submarines. Sonar works this way: When a pulse of ultrasonic waves is sent through the water from a ship equipped with sonar, an echo of the same frequency returns to the sonar apparatus from any solid object in the path of the waves. Since they are not diffracted, the direction from which the echo returns reveals the object's position. The distance, say, of a submarine from the ship can be calculated from the length of time that elapsed between the sending of the original pulse and the return of the echo. The device is able to repeat the transmitting and receiving operations many times per second so that extremely brief periods of time may be measured. Submarine hunters were sometimes confused because the sonar system even picked up ultrasonic noises made by large schools of shrimps deep in the sea.

As you can see, sonar actually works on much the same principles as radar. The latter device is of no help under water, however, as it uses radio (electromagnetic) waves. These waves do not pass through water easily, whereas water is one of the best conductors of sound.

In peacetime, sonar is helpful to navigators in making soundings. If an ultrasonic beam is aimed straight down toward the ocean bed, the depth of the water can be figured from the length of time it takes the beam to go down and be echoed back. Another peacetime use of sonar is on fishing boats because the device can locate schools of fish.

In 1951, Wayne M. Ross, a Seattle engineer, developed a simplified but even more sensitive sonar system. With this it is possible not only to locate schools of fish but also to identify the fish by determining the size of each school and the depth at which it is swimming. The device promises to be of even greater importance in the navigation of narrow, rocky channels because the echoes bounce back from hidden shoals and from coastlines. The ultrasonic beam can be sent in any direction through the water, and the pattern of the echoes is displayed on a screen, much like radar. Ross's invention also records information in two other ways. The returning echoes are translated into audible sounds, over a loudspeaker, that a trained operator can easily recognize. A solid wall gives out a hard, clipped ping. Sounds from a smooth beach or a hidden sand bar are drawn out, as if someone were scratching granite with his fingernails. At the same time, automatic pen-and-ink records are made of all the echoes that appear on the screen and are heard over the loud-



A high-speed photograph of the movement of water in a tank through which sound waves with a frequency of nearly 3,000,000 cycles per second are being sent. The waves are coming from a barium-titanate crystal, clamped between wires.

General Electric

speaker. Thus there is a permanent record.

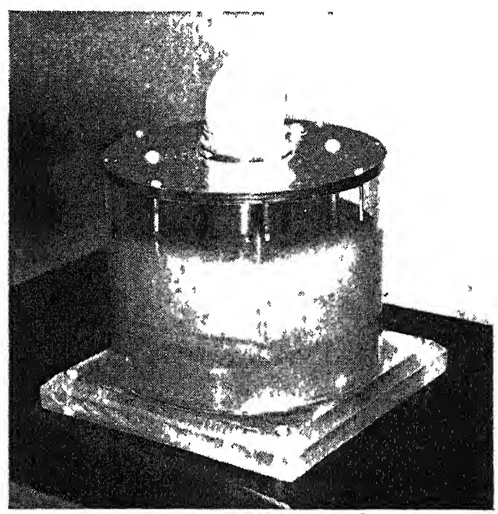
Scientists have discovered several ways of producing ultrasonic waves. The one most used for sending these waves through solids or liquids depends on a peculiar property of certain crystals, such as quartz, Rochelle salt (sodium potassium tartrate) and ammonium dihydrogen phosphate This property is called the piezoelectric effect (from the Greek *piezein,* meaning "to press," plus "electric"). The effect was discovered by Pierre and Paul Curie in 1880.

The effect works like this: When pressure, which may be applied by weights, is brought to bear on such a crystal plate cut in a certain way, the plate becomes electrically charged. The amount of current generated is in proportion to the amount of pressure applied. Moreover, if the charged plate is stretched, the charge will be reversed. By alternate compression and stretching, therefore, an alternating current will be set up. The piezoelectric effect will work in the opposite way, once the natural frequency of the crystal is known. If an alternating current of the same frequency as a crystal's natural one is applied to the crystal, it will expand and contract in rhythm with the changes in the direction of the current.

The scientist produces ultrasonic waves by applying electricity to a crystal. Usually, small metal plates are attached to the crystal in an ultrasonic device and they move up and down in the same rhythm. This, in turn, sets up similar vibrations in the medium in which the apparatus is immersed — often a dish of light oil. With certain crystal cuts, their length or thickness is alternately increased and decreased and the waves travel in a longitudinal direction — that is, along the direction of the beam of sound. There are other crystal cuts from which the waves travel at right angles to the direction of the beam.

Another way of creating ultrasonic waves involves the use of an iron or nickel rod. A solenoid, which is a tubular coil for the production of a magnetic field and acts like a magnet, is placed around the bar. When a high-frequency alternating current is sent through the solenoid, the bar is magnetized in such a way that there are slight changes in the length of the bar in rhythm with the alternation of the current. The vibration thus set up in the bar is communicated to whatever medium surrounds it. Such a variation in length because of magnetization is called magnetostriction.

The strangest feature of these ultrasonic waves is that in the range of very high frequencies they have tremendous power. Ordinary sound waves have energy, but it is usually rather weak. Even a million persons all talking steadily for an hour and a half in a huge hall would produce only enough sound energy, converted into heat,



General Electric

Scrambling an egg without breaking the shell. Waves with a frequency of one million cycles pass from the oil bath to the water in which the egg rests, break down the egg's contents and cook it.

to produce a single cup of hot tea. Yet, in the experiments of Professor Langevin, of whom we spoke earlier, small fish swimming through the ultrasonic beams were killed instantly. When one of the professor's assistants held his hand in the path of the waves — only for an instant, you may be sure — he felt agonizing pain, as if his very bones were being heated.

What would we see in a laboratory where scientists are experimenting with ultrasonic waves? The focus of our attention

Sperry Products, Inc.

The box on top of the tread is an ultrasonic device called a reflectoscope. It is being used to test the take-up shaft on a giant power shovel. The reflectoscope sends short bursts of "silent" sound into the shaft, and any echoes that returned to the instrument would indicate cracks in the shaft.

would probably be a dish of oil. Immersed in it is a crystal, to which metal plates are attached, and from the plates there are wires connected with a maze of apparatus. As the electric current is turned on, there is an eerie hum. Watching the dish of oil, we see the surface suddenly begin to tremble. Slowly a mound forms and, so violent is the force, the oil bubbles and froths like boiling lava in an active volcano. At the climax, drops of oil fly up from the mound and make a little fountain that may be as high as twelve inches.

In one experiment, a small glass rod, pointed at one end, is dipped into the oil from above so that it touches the metal plates. If a piece of wood is held against the rod, smoke soon begins to spiral upward. After only a few moments, a hole is completely burned through the wood.

The evidence of great force is before our eyes, but where is it coming from? The metal plates move through distances of only ten thousandths of an inch. In fact, the plates appear to be still. Nevertheless, they change their direction at the enormous rate of hundreds of thousands of times per second. An object soaring out into space from the earth at such a rate of speed as this would be about a million miles away in ten seconds. It is the tremendous rapidity of the vibrations that gives such ultrasonic waves their power.

Both science and industry are beginning to harness this power. One device, called a reflectoscope, sends short bursts of "silent" sound into a metal object, such as a casting, searching out flaws. A quartz-

crystal mechanism is placed against the object, with only a film of oil between them. The reflection of the high-frequency beam sent out by the crystal is picked up by the crystal, now acting as a microphone. Electronic switching is necessary (as in sonar) because the alternate use of the crystal as transmitter and receiver takes place in millionths of a second. Any flaws in the metal bounce back as echoes and flash on a cathode-ray screen, a kind of fluorescent screen, showing the location of the defects.

Flaws in automobile tires may be detected by a similar method. The tire is immersed in water between a transmitter of ultrasonic beams and a receiver. Rubber will transmit a sound wave from water with little reflection so that any echoes indicate a defect in the rubber.

Very high-frequency sound waves can make two liquids emulsify that ordinarily would not mix. For instance, alloys of iron and lead, aluminum and lead, aluminum and cadmium and so forth can be made to mix in the liquid state and kept mixed until they solidify. New bearing materials are being produced in this way. Another application of this effect is to make photographic emulsions stable and of the same consistency throughout.

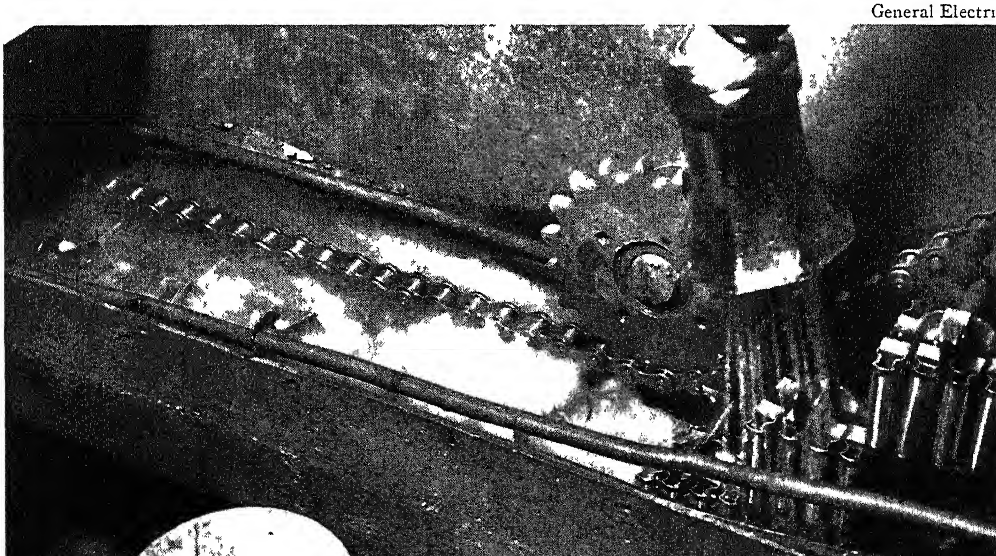
Another use of high-power ultrasonics is to make solid and liquid particles in mist, dust and smoke clump together. Factories that make lampblack, for instance, an ingredient of varnishes, paints and some kinds of ink, are installing ultrasonic generators in the flues of their smokestacks. Ultrasonic vibrations push the lampblack particles together and they then drop down the chimney instead of escaping into the outside air Around airports and harbors, ultrasonic waves can disperse fog and mist. It is even possible that large industrial areas overhung with palls of smoke and soot may be cleared by the same method.

Some kinds of chemical reactions are speeded up under the influence of ultrasonic waves They may also break up long-chain polymers — molecules with a highly complicated structure.

In the United States in 1950, a patent was issued for an ultrasonic device that helps blind persons to avoid obstacles. The waves are sent out from a mechanism in a walking cane. Echoes from any object ahead are picked up by a receiver in the cane. Their energy is converted into electric pulses that travel by wire to the per-

An ultrasonic "bath" that cleans shaver heads, for electric razors. The heads move through a trough filled with cleaning fluid. At the same time ultrasonic waves, generated by a crystal, are sent through the fluid. These clean small openings and corners where the fluid alone would be ineffective

General Electric

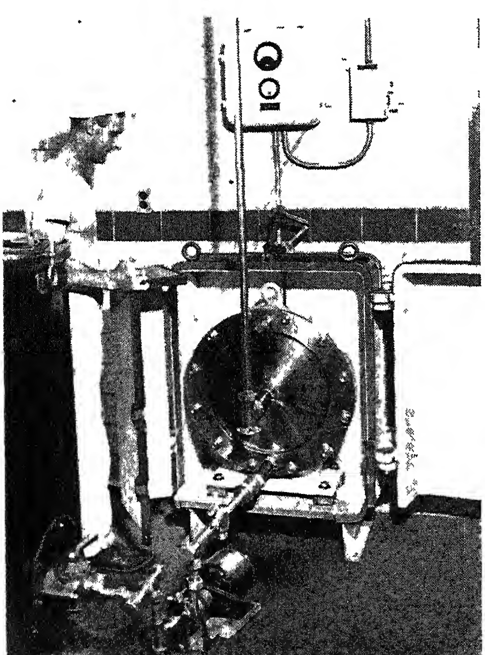


son's ear where, by means of a kind of microphone, the pulses are translated into audible sound.

Quicker and better laundering is another very practical use of ultrasonics. The intense vibrations break down the attraction between dirt particles and fabrics and shake the grime loose.

Ultrasonic waves, as we have seen, can affect living organisms, although the reason for the effects is still rather obscure. Seeds, for example, have been treated with "silent" sound. In one case, it was reported that potato plants so treated blossomed a week ahead of time and their yield increased 50 per cent above the crop from untreated plants.

Living cells may be literally shaken to pieces by ultrasonic waves. Germs may be killed, and milk exposed to waves of high intensity is pasteurized in a few seconds. We pointed out that small fish had been killed by swimming through the ultrasonic beams produced by Professor Langevin's apparatus. Frogs and mice have also been killed by silent sound.



Raytheon

In this machine, an oscillator, milk is homogenized by "silent" sound. It breaks up fat globules and thus makes the fat mix with the rest of the milk.

In some kinds of surgery, ultrasonic beams may eventually take the place of knives and scalpels, performing an operation much more quickly and with less danger to the patient. Experimenting with dogs and rabbits, surgeons have shattered gallstones into fragments in fifteen seconds by the use of intense beams. The tissues around the gallstones were not damaged, and the fragments of the stones were easily eliminated through natural channels. In these operations the beam was transmitted through water, which is elastic. Living tissue is as elastic as water — it seems to "roll with the punch" — stretching without splitting under the impact of the beam. Only the solid gallstones were cracked into tiny pieces. Kidney stones might be treated in the same way.

Brain operations, usually long and delicate, are another ultrasonic possibility. At Columbia University, quartz crystals for ultrasonic generators were cut so that the waves could be focused on a particular spot inside the brain of a dog or a cat. The energy of such a concentrated beam can be as much as 150 times as forceful as that of an unfocused beam, and it can destroy a selected brain area in a few seconds.

Ultrasonic waves can have peculiar effects on human beings besides those we have mentioned. Just as a piece of wood is burned if it is held against the glass rod touching the vibrating metal plates, so would your fingers be burned if you touched the rod. Even stranger and rather frightening is the fact that if a person stands in the path of ultrasonic waves of high intensity, he feels confused and depressed and loses control of his movements. A mathematician reported that for several days after she had been subjected to such waves, she was unable to solve even the most simple problem in arithmetic.

Though the existence of ultrasonic waves has been known for many years, the development of the science of ultrasonics is fairly recent and received its greatest impetus after World War II. It is likely that we are only on the threshold of the mysterious house of "silent" sound.

THE DISCOVERY OF NEPTUNE AND PLUTO

Problems That Confront Astronomers in Determining the Orbit of a Planet

TO the ancients a planet meant a wandering body as opposed to the "hairy stars" called comets, the other bodies that wander among the heavenly host of fixed stars. There were thus known to the ancients seven orderly wandering bodies, Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn.

The comets, bizarre and erratic wanderers, were regarded with superstitious awe and dread. Even the renowned and gifted Tycho Brahe in 1572 believed them to be in our atmosphere, though the results of his own work, in the hands of Kepler and Newton, did much to dispel this illusion.

After the new understanding of the universe made possible by the labors of Tycho Brahe, Kepler and Galileo, the true place of the sun as the important member of the solar system began to dawn upon man's mind. Crowned as these labors were by the sublime achievement of Newton, it became clear that the distinction of planets, as wandering stars, was no longer valid.

Copernicus conjectured, and Kepler and Galileo established the fact, that the earth was one of the six then known planets, dark, cold bodies revolving around the sun in ordered paths, the law of whose ordering was divined and established by the immortal Newton.

In the century following Newton's death, that illustrious group of French and other continental mathematicians, among whom were such men as Euler, Clairaut, the Bernoullis, LaGrange, Laplace, Bessel and Gauss, carried forward the knowledge to which Newton had so brilliantly contributed with his theory of gravitation.

While this work of completely explaining the mechanism of the solar system was in progress, Sir William Herschel commenced the more difficult task of unraveling the mysteries of the greater universe of stars and nebulae in which the solar system is so minute a part. He made the first steps in finding the space distribution and motions of stars and systems of stars, and, in the course of his second review of the heavens with a seven-foot telescope, which he had recently completed, on March 13, 1781, perceived a small star near H Geminorum, visibly larger than the rest. He suspected it to be a comet, but further observations during the following four months led Lexell to believe that it was a planet. It was not, however, until nearly two years later that Laplace computed elliptic elements for its orbit and showed that it was a planet—the one now called Uranus.

Since that time two new planets have been discovered—Neptune and Pluto. The existence of Neptune was deduced by John Couch Adams and, separately, by Urbain J. J. Leverrier; the planet was first spotted in the telescope by Leverrier's friend, J. G. Galle, in 1846. In 1905, the American astronomer Percival Lowell deduced the existence of a new planet which he called planet X, or the Trans-Neptunian planet because it occurred beyond Uranus. It was discovered in 1930 and given the name of Pluto. The circumstances under which the two planets were discovered were so similar that it will be interesting and instructive to set them forth in detail.

"The theory of gravitation is not more remarkable for the sublimity of its results

than for its varied and effective character, when considered as an instrument applicable to the discovery of truth. By unfolding its principles, the astronomer, without leaving his observatory, has been enabled to determine the distances of the Sun and Moon from the Earth, to weigh the planets as in a balance, and to educe order and stability from the countless irregularities of their motions. It has conducted him to a knowledge of the figure of the Earth by merely watching the motion of the Moon or the swinging of a pendulum, and it supplies the means of ascertaining the figures of the celestial orbs without measuring their apparent dimensions. The eccentric aberrations of comets, the ebbing and flowing of the tides, and the oscillations of the atmosphere, all equally attest the value of its guidance in exploring the hidden operations of nature. But a still more striking triumph of this magnificent theory was reserved for our own day, when the mathematician, by meditating in his chamber upon its principles, has succeeded in revealing the existence of a new planetary world, vastly exceeding the earth in magnitude, which had hitherto escaped the scrutinies of astronomers, aided by all the powerful appliances of optical science." So wrote Robert Grant in his "History of Physical Astronomy" (1852) written when mankind had recently learned of the finding of Neptune in the position mathematically independently predicted by Adams in October 1845 and seven months later by Leverrier, from the perturbations produced in the motion and orbit of Uranus.

The discovery of the Trans-Neptunian planet is so like in almost every respect that of Neptune itself, that by changing dates and names of the principal actors, one might almost copy the earlier account and have it substantially accurate. Except that only one man made the mathematical calculation that led to the prediction of the place among the stars in which the new planet would be found, there would be only two major changes necessary: first, the problem of the Trans-Neptunian planet is immensely more difficult than was the case of Neptune because its disturbing action on Uranus produces only about one one-hundredth of the effect of Neptune; and, second, because of the greater remoteness and smaller size, its extreme faintness multiplies by at least six hundred the difficulty of seeing it.

By 1790 Uranus had been observed over a sufficiently long arc to enable its orbit to be determined with some accuracy and the Academy of Sciences of Paris proposed the theory of its motion as the subject of a prize. By a skillful use of the observations made since its discovery, Delambre computed the elliptic elements of its orbit and was the successful competitor for the prize. By computing from the elliptic elements the position occupied by the planet during the time when famous observers were making the observations required as the basis for the compilation of accurate catalogues of stars, Delambre found that Uranus had been observed as a star since 1690 by Flamstead, Bradley, Mayer and Lemonnier. He employed these earlier observations in calculating tables of Uranus which continued for a few years to agree with the observed positions of the planet with reasonable accuracy.

As time passed, the discrepancy between the tables and observed positions increased, until astronomers felt that the theory should be revised and employed in the calculation of new tables. Bouvard undertook to do this, but he found that no orbit could be made to fit the early observations by Flamstead, Bradley, Mayer and Lemonnier and those made after Herschel's discovery of the planet. He accordingly computed an orbit based only on the observations between 1781 and 1820 and computed tables based upon this orbit. These tables, like Delambre's, gave very close accordance with observations for a few months, but after only a few years the discordances again became intolerable.

Bouvard had made remarks during his work on the new tables for Uranus which would justify one in concluding that he then suspected the existence of a Trans-Uranian planet. The idea of a planet beyond the one farthest known was not new, for even before the discovery of Uranus, Clairaut, in 1759, was led to suspect a Trans-Saturnian planet, due to certain effects on the orbit

of Halley's comet, which returned according to Halley's prediction that year but not at exactly the time that Clairaut figured that it should, after allowing for the disturbing action of Jupiter and Saturn. Again in 1835, on the next return of Halley's comet, Valz suggested that a Trans-Uranian planet had affected the motion of Halley's comet so that its return to perihelion in 1835 differed from its computed value more than it should, after allowing for the disturbing action of Jupiter, Saturn and Uranus. Even in this regard, history repeats itself, for W. H. Pickering, in a memoir of the Harvard College Observatory, published early in this century, predicts more than one Trans-Neptunian planet as a result of investigations of cometary aphelia.

By 1841 the discrepancies between the observed and computed positions and distance from the sun of the planet Uranus were more than could possibly be attributed to errors of the observations which Bouvard had used in computing the elements of the orbit. Long before this Bouvard became convinced that there was a Trans-Neptunian planet.

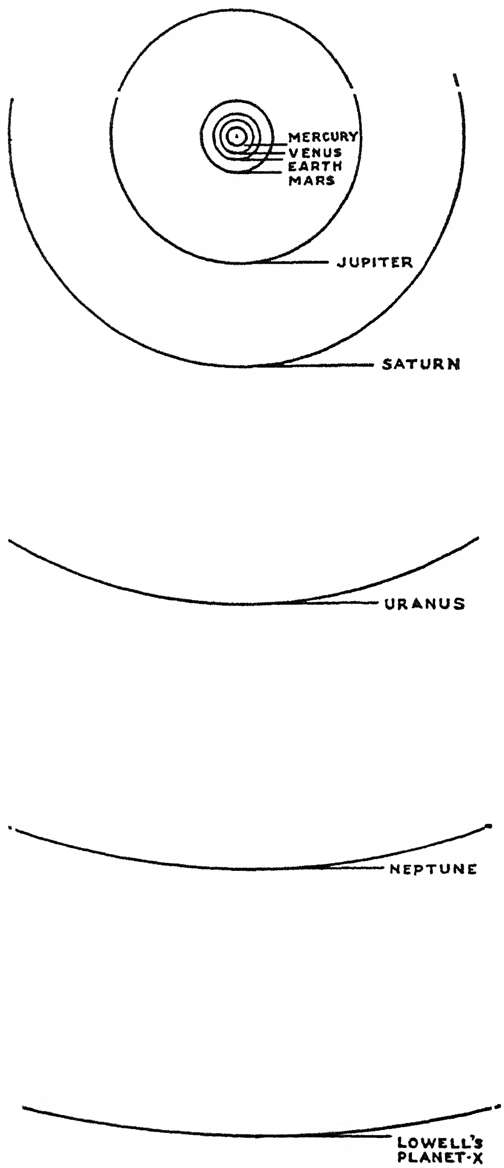
In 1842, the illustrious Bessel expressed to Sir John Herschel, son of the discoverer of Uranus, the conviction that the irregularities in the motion of the planet were due to the disturbance caused by the attraction of the unknown body. He planned to undertake to find the position of the Trans-Uranian planet which was thought to be the cause of the irregularities, as soon as he should obtain leisure from other researches in which he was engaged. He went so far as to request Flemming to reduce with great care all the observations of Uranus. This Flemming did, but unfortunately, Bessel was soon afterwards seized with the illness which proved fatal to him and further work on the problem was abandoned by Flemming.

On July 3, 1841, John Couch Adams, then an undergraduate in St. John's College, Cambridge, entered the following memorandum in his note book:—"Formed a design, in the beginning of this week, of investigating as soon as possible after taking my degree, the irregularities in the motion of Uranus which are yet unaccounted for; in order to find whether they may be attributed to the action of an undiscovered planet beyond it, and, if possible, thence to determine approximately the elements of its orbit, etc., which would probably lead to its discovery."

Adams, having taken his degree in January, 1843, proceeded to enter upon this work. The problem which he set himself may be stated as follows: Assuming that Uranus was disturbed by some unknown body, to determine the position of the latter, its mass and the elements of its orbit, by means of the irregularities it produces in the motion of the disturbed planet.

By Oct. 1, 1845, seven months before any one else had arrived at a similar conclusion, Adams had completed his self-imposed task and by means of his solution had discovered theoretically the existence of Neptune, and had assigned to the then unknown body a place in the heavens which was subsequently found to differ little more than one degree from its actual place. All that was now wanting to assure him the undivided honor of one of the greatest discoveries recorded in the annals of astronomical science was some keen observer to carefully search the region in which his computations showed that the planet should be. If such observations had been undertaken, it would undoubtedly have resulted in the discovery of Neptune nearly a year earlier than it was actually seen. Airy, the Astronomer Royal at the Greenwich Observatory was interested in the work Adams had done, and would undoubtedly have taken active steps to have a search made for the planet in November 1845, had Adams promptly answered a question he had raised regarding the correction to the distance of Uranus from the sun. Adams had implicitly answered the question in his first communication to Airy and so did not consider it important to answer the question. It was not until nine months later, when the results of Adams were verified by the researches of Leverrier, that Airy set in motion the steps which led to the detection of Neptune in the place predicted by Adams. Leverrier commenced his researches about the time Adams had fin-

ished his first paper. He was not aware of what Adams had done until after his own papers were published and Neptune had been found by his friend Galle, as the result



Relative sizes of the orbits of Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Lowell's Planet X, to scale ⅛ inch = distance of Earth from Sun. The dot representing Sun is four times too large.

of his theoretical prediction of its position. Galle received Leverrier's letter telling him where to find the planet on Sept. 23, 1846, and on the same night Galle found the planet, just barely less than one degree from the place assigned by Leverrier. This was made possible because the Berlin Observatory had just received a new and complete map of the stars in the very region where Leverrier indicated the planet would be.

On hearing, on Oct. 1, 1846, of the discovery of Neptune, Challis, who began searching in the place indicated by Adams on July 29, 1846, found that he had observed the planet twice by August 12, though he had been observing only four nights. Had he compared observations of the same regions on each night, he would have anticipated Galle by six weeks in the discovery of the planet, and, even at that late date, brought to Adams the prior credit for its theoretical discovery.

Enough has been said to show that to Adams and to Leverrier belong equally and independently the theoretical discovery of Neptune, and it was a fortunate accident that the Berlin astronomers were able, because of the earlier reception of a map of the region where Neptune was, to be the first to know that the planet was seen.

An explanation of the problem which presented itself to Adams and Leverrier, in the case of Neptune, and to Leverrier, Gaillot, Law and Lowell, in the case of the Trans-Neptunian planet, will not be out of place here.

Six quantities, called elements of the orbit, are needed to define the position, size and shape of the elliptic orbit of a planet, Uranus in our problem, which lies in the plane of the earth's orbit, and to tell where the planet will be in such elliptic orbit at any given time. If these six quantities are known, and Uranus and the sun were the only bodies in the universe, then it would be possible to compute the exact position of Uranus at any past or future time. It would also be practically possible to compute the position of Uranus at any past or future time as long as a limited number of known bodies, moving in known orbits, were also moving around the sun. In the latter case the problem would be much more difficult. But now suppose that, with all the known, there is an unknown body influencing Uranus. Its observed positions

would be different on account of it, and hence the orbit computed from them would not be correct, because the effect of other bodies besides the sun must be allowed for before computing the elliptic elements. The effect of Jupiter and Saturn can be allowed for, but in the case considered by Adams and Leverrier, Neptune and Trans-Neptunian planets could not be allowed for. Leverrier, Gaillot, Law and Lowell could allow for disturbing action by Jupiter, Saturn and Neptune but not for the Trans-Neptunian planet. Hence it is necessary to consider both the elements of the orbit of Uranus and the planet X unknown, making in all twelve unknowns, if only one planet beyond Neptune is considered. Theoretically, if we had six observed positions of Uranus, we could express these in terms of the twelve unknown elements, two equations for each position, thus giving twelve equations with twelve unknowns which every high school student should recognize as a problem which can be solved. The practical problem is, however, almost immeasurably more difficult because all of the observed positions are subject to the disturbing actions of all unknown bodies as well as to the small but inevitable errors of observation. We really have hundreds of equations with twelve unknowns and the problem is to find values of these unknowns, such that when they are substituted in the equations, none of the equations are exactly satisfied, but the sum of the squares of all the small residuals is smaller than any other set of values of the unknowns would give.

As Lowell says:—"The problem which confronted Adams and Leverrier was the simplest possible case of the general problem. And this for two reasons. In the first place Neptune was relatively near Uranus and secondly, his orbit was nearly circular." Again Lowell says in his "Memoir on a Trans-Neptunian Planet": "At the present time no such simple problem confronts us. . . . We cannot use Neptune as a finger post to a Trans-Neptunian planet as Uranus was used for Neptune, because we do not possess observations of Neptune far enough back. . . . A disturbed body must have pursued a fairly long path before the effects of perturbation detach themselves from what may well be represented by altering the elements of the disturbed. . . . Neptune has not been known long enough to do this."

As Uranus is the farthest body from the sun which fulfilled this condition, Lowell used the unaccounted-for discrepancies between observed and tabular positions of Uranus as a basis for his investigation. His Memoir was finished in 1914 and printed in 1915, though he had published the results of some preliminary investigations several years earlier and search for

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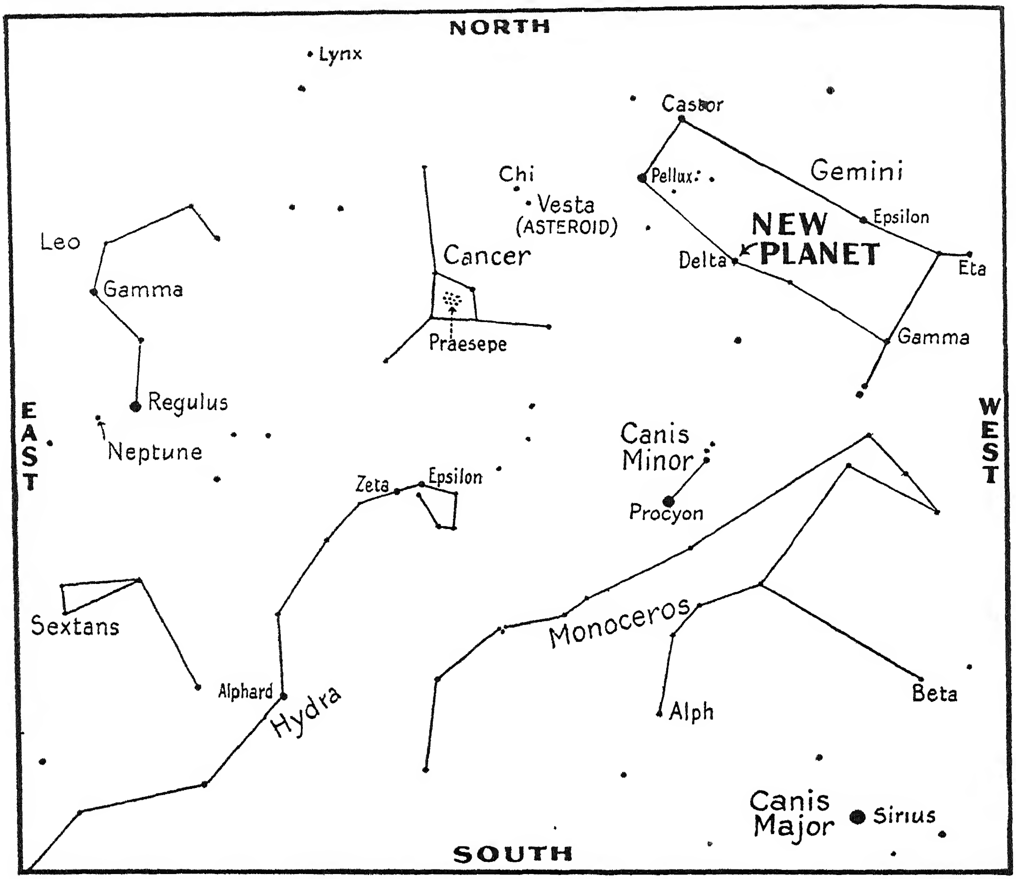
PERCIVAL LOWLLL

the Trans-Neptunian planet was begun at the Lowell Observatory in 1905, as a result of his theoretical work on the dynamical evidence of a planet beyond Neptune.

In his earlier work upon this problem, Lowell followed essentially the classical method used by Leverrier, but later he developed a new, more complete and exact method which is used in his Memoir. The Memoir is so technical and difficult that it is impossible for those not familiar with Celestial Mechanics and the method of Least Squares, to follow it.

Suffice it to say that the observers at the Lowell Observatory used the position com-



STAR CHART, DRAWN BY H. S. RICE OF THE AMERICAN MUSEUM OF NATURAL HISTORY
Showing the position of the new planet, near the star Delta in Gemini, on March 17, 1930, four days after the announcement of its discovery.

puted from the elements of its orbit as derived in Lowell's Memoir of 1914 as a guide in searching for the planet. The object seen conforms approximately both in position and motion to Lowell's theoretical Planet X. It was named Pluto in honor of the god who chose the outer regions, and its symbol is "PL," the first two letters of Pluto and the initials of Percival Lowell. We quote here the observation circular sent out by the Lowell Observatory:

"The finding of this object was a direct result of the search program set going in 1905 by Dr. Lowell in connection with his theoretical work on the dynamical evidence of a planet beyond Neptune. (See L. O. Memoirs, Vol. 1, No. 1, 'A Trans-Neptunian Planet', 1914.) The earlier searching work, laborious and uncertain because of the less efficient instrumental means, could be resumed much more effectively early last year with the very efficient new Lawrence Lowell Telescope specially designed for this particular problem. Some weeks ago, on plates he made with this instrument, Mr. C. W. Tombaugh, assistant on the staff, using the Blink Comparator, found a very exceptional object, which since has been studied carefully. It has been photographed regularly by Astronomer Lampland with the 42-inch reflector and also observed visually by Astronomer E. C. Slipher and the writer with the large refractor.

"The new object was first recorded on the search plates of January 21 (1930), 23rd, and 29th, and since Feb. 19th it has been followed closely. Besides the numerous plates of it with the new photographic telescope, the object has been recorded on more than a score of plates with the large reflector by Lampland, who is measuring both series of plates for positions of the object. Its rate of motion he has measured for the available material at intervals between observations with results that appear to place the object outside Neptune's orbit at an indicated distance of about 40 to 43 astronomical units. During the period of more than seven weeks the object has remained close to the ecliptic; the while it has passed from 12 days after opposition point to within about 20 days of its stationary point. Its rate of retrogression, Mar. 10 to 11, was about 30″ per day. In its apparent path and in its rate of motion it conforms closely to

the expected behavior of a Trans-Neptunian body, at about Lowell's predicted distance. There has not been opportunity yet to complete measurements and accurate reductions of positions of the object requisite for use in the computation of the orbit but it is realized that the orbital elements are much to be desired and this important work is in hand.

"In brightness the object is only about 15th magnitude. Examination of it in the large refractor—but without very good seeing conditions—has not revealed certain indication of a planetary disk. Neither in brightness nor in apparent size is the object comparable with Neptune. Preliminary attempts at comparative color tests photographically with large reflector and visually with refractor indicate it does not have the blue color of Neptune and Uranus, but hint rather that its color is yellowish, more like the inner planets. Such indications as we have of the object suggest low albedo and high density. Thus far our knowledge of it is based largely upon its observed path and its determined rates of motion. These, with its position and distance appear to fit only those of an object beyond Neptune, and one apparently fulfilling Lowell's theoretical findings.

"While it is thus too early to say much about this remarkable object and much caution and concern are felt—because of the necessary interpretations involved—in announcing its discovery before its status is fully demonstrated; yet it has appeared a clear duty to science to make its existence known in time to permit other astronomers to observe it while in a favorable position before it falls too low in the evening sky for effective observation."

V. M. SLIPHER.

Flagstaff, Arizona.
Mar. 13, 1930.

The new body has since been observed at nearly all of the observatories having telescopes capable of seeing it, and has been photographed by telescopes as small as 8½ inches aperture.

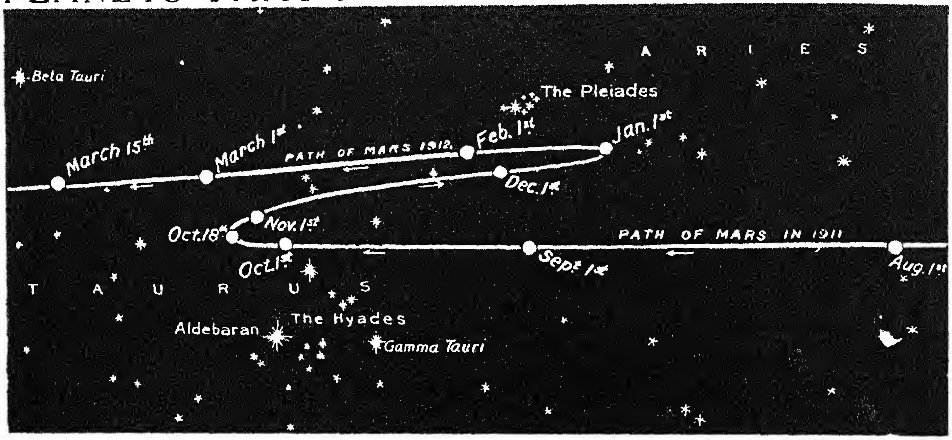
Not only was the problem of finding the elements of the orbit of Lowell's planet much more difficult than was the same problem for Neptune, but because of its great remoteness and consequent faintness, the problem of locating the planet itself is much more difficult. There are only about two stars per square degree as bright or brighter than Neptune but there are one hundred to one thousand stars per square degree as bright or brighter than Pluto is. Since its brightness was not certainly known, it was necessary to scrutinize objects two or three magnitudes fainter than its estimated magnitude, which means to distinguish it among a possible five thousand stars per square degree, which do not differ much from the planet in apparent brightness. To distinguish one object which is slowly changing its position, from week to week, among some ten or twenty thousand objects of the same general appearance on the same photographic plate, is no easy task even with all the appliances now available to aid in such a search.

Though the planet looks very faint to us, we must be careful not to assume that at its distance the sun fades to the apparent brightness of the brighter stars. If, as appears to be the case, its distance from the sun is not greatly different from the value assigned by Lowell, it is less than one six-thousandth as far from the sun as the nearest known star. The amount of sunlight on it will be equal to what two hundred and fifty full moons in our sky would give to us. Hence, if in some way the planet could be warmed sufficiently for a comfortable abode, we could manage to see our way around and enjoy the pleasures which the sense of sight makes possible to us.

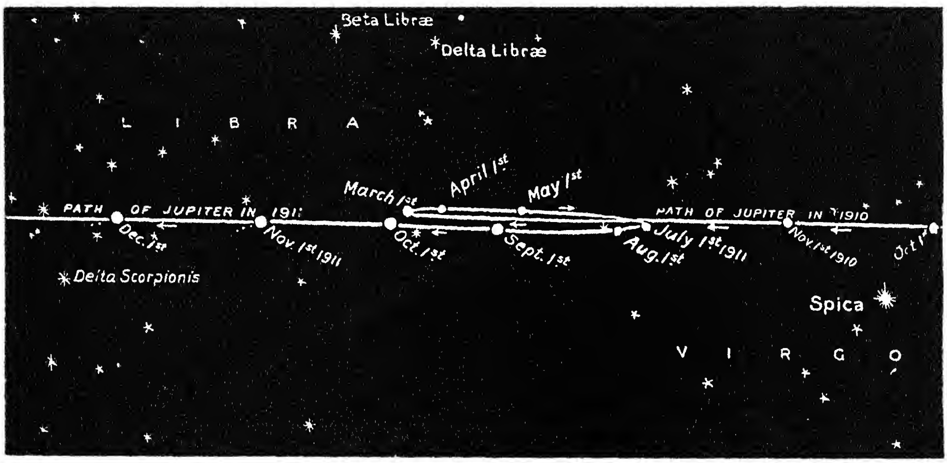
The calculation of Pluto's orbit led to a search of photographic plates. It was found that Pluto had been photographed, though not detected, as far back as 1914, and that it was to be seen on a plate that had been taken at the Lowell Observatory in 1915. Pluto is about 3,700,000,000 miles from the sun. A Plutonian year, which is the time taken by the new member of our solar system to complete its orbit around the sun, is about 248 years. Pluto's diameter is $\frac{3}{4}$ that of the earth.

It is certainly very fitting that this body, sought by Lowell as his Planet X, should be discovered at the Observatory which he founded and endowed, and to which he gave not only his worldly possessions, but the best years of a rich and gifted personality.

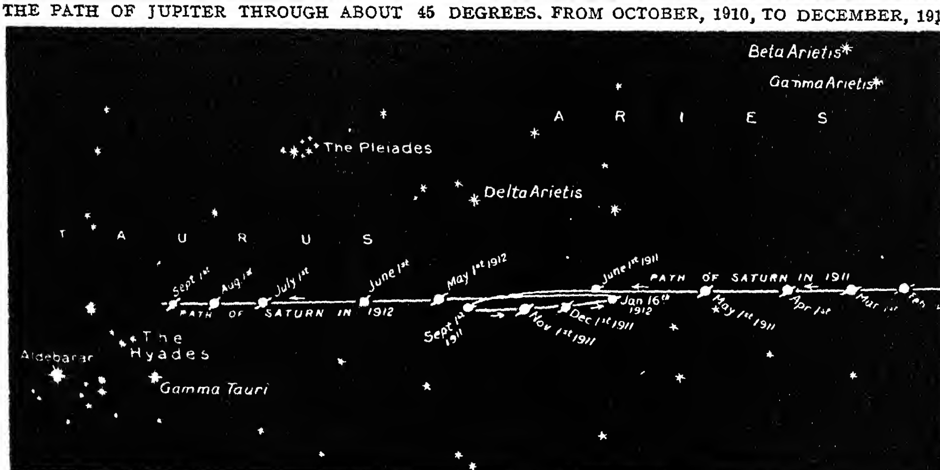
PLANETS THAT SEEM TO MOVE BACKWARDS



THE PATH OF MARS THROUGH ABOUT 45 DEGREES OF THE HEAVENS, FROM AUGUST, 1911, TO MARCH, 1912



THE PATH OF JUPITER THROUGH ABOUT 45 DEGREES. FROM OCTOBER, 1910, TO DECEMBER, 1912



THE PATH OF SATURN THROUGH ABOUT 40 DEGREES, FROM FEBRUARY, 1911, TO SEPTEMBER, 1912

Each of these star-maps represents an area of the sky about 45 degrees wide, or a band about one quarter across the dome of the sky. By comparing the distances traversed by each planet with the times occupied, it will be seen that the speed and the amount of retrograde movement diminish relatively to the distance of each planet from the earth. This fact gave the early astronomers an idea of their relative distances. It is important to note that these pictures do not show the real motion of the planets, but the apparent motion, which is due to the combined motion of the earth and the planet in question. This motion was ingeniously explained in the ancient Ptolemaic system by what were called epicycles, which are illustrated on page 870.

A SUB-LORD OF THE HEAVENS

Size, Density, Travels, Velocities, Satellites and Spots of the Great Planet Jupiter

THE DISCOVERY OF THE SPEED OF LIGHT

AFTER the asteroids we come to Jupiter, which is by far the greatest of the planets, and differs widely from those members of the sun's family we have already considered. The asteroids are interposed between two groups of planets, with four in the inner and five in the outer group. The two groups are on the whole very unlike, though the members of each, with the exception of Pluto, resemble one another. Mercury, Venus, the Earth and Mars, known as the terrestrial planets from their general similarity to the earth, are comparatively small, dense in structure, near together and poor in satellites. Pluto, the outermost planet of the outer group, approximates the earth in size.

Outside the terrestrial planets are the asteroids, and outside these again are Jupiter, Saturn, Uranus, Neptune and Pluto. The first four, called the major planets because of their great size as compared with the earth, are far less dense in structure and are situated much farther apart than the terrestrial planets.

Although we thus group the four inner planets together as terrestrial planets, on account of their general similarity, there are, as we have seen, great differences among them. The same is true of the four major planets. There is similarity among them, but no sameness. Though all four are great, they still differ widely in size.

Perhaps Sir John Herschel's illustration of the dimensions and distances of the planets gives the clearest impression of the solar system, and of the relative proportions of its worlds. He imagines a globe two feet in diameter placed in the middle of a great field. This globe represents the sun.

"Mercury will be represented by a *grain of mustard seed* on the circumference of a circle 164 feet in diameter for its orbit; Venus, a *pea* on a circle of 284 feet; the Earth, also a *pea* on a circle of 430 feet; Mars, a rather large *pin's head* on a circle of 654 feet; Juno, Ceres, Vesta and Pallas (and other asteroids), *grains of sand* in orbits of 1000 to 1200 feet; Jupiter, a *moderate-sized orange* on a circle nearly half a mile in diameter; Saturn, a *small orange* on a circle of four-fifths of a mile; Uranus, a *full-sized cherry* or *small plum* upon the circumference of a circle more than 1½ miles, and Neptune a *good-sized plum* on a circle about 2½ miles in diameter." If we now include Pluto, discovered since Herschel's time, as a *pea* on a circle about 3¼ miles in diameter, we have a picture which helps the mind to realize how vast are the distances in space as compared with the dimensions of the planets. These distances, however, are almost as nothing compared to stellar distances. On the above scale Proxima Centauri, our nearest stellar neighbor, would be over 11,000 miles distant.

These major planets, then, are to the terrestrial planets as oranges and plums are to peas. Jupiter, the giant planet, is larger than all the others put together. Its mean diameter is 86,500 miles, which is nearly 11 times the diameter of our globe; but this gives no adequate idea of Jupiter's enormous size, for its superficial area is 119 times as great as that of the earth, and its volume 1300 times. On the other hand, as its density is less than one-fourth that of the earth, its mass is very small for so great a volume, only about 316 times that of the earth.

Strange contrasts between Jupiter and the earth in density and movement

The force of gravity on the surface of Jupiter is 2 64 times as great as that on the earth's surface, so that a mass weighing one pound on earth would weigh two pounds ten ounces on Jupiter. This planet, with a diameter about one-tenth that of the sun, a circumference greater than the distance between the earth and the moon, and a density almost exactly the same as that of the sun, is obviously very different from our earth. The huge size and low density suggest that Jupiter is still far from the solid state.

The shape of Jupiter, like that of the earth, is a globe flattened at the poles and bulging out at the equator, but the flattening and bulging are much greater in the case of Jupiter. As seen in the telescope, the outline of Jupiter is conspicuously elliptical, and measurements show that the polar diameter of 82,789 miles, and the equatorial diameter of 88,698 miles, are to one another as 14 to 15. This wide departure from the spherical form is due to the great rapidity of the planet's spinning, to its huge size, and to the powerful centrifugal force which is consequently set up in the equatorial regions. As a result of these same conditions, the force of gravity at the poles of Jupiter exceeds the force of gravity at its equator in the proportion of 6 to 5. It will be remembered that there is a similar difference between the gravitative force at the poles and at the equator of the earth, but in this case the difference is only in the proportion of 191 to 190.

The dizzy spinning of Jupiter as it travels round the sun in twelve years

Jupiter travels round the sun at the rate of 8 miles in a second, in a vast orbit which is completed in a little under 12 years. The earth, traveling round the sun in an orbit far within Jupiter's, comes into line with it once in every 399 days. Jupiter's distance from the earth varies from a maximum of nearly 600,000,000 miles to a minimum of about 369,000,000 miles, and its brightness at the nearest point is nearly three times its brightness when farthest away. The mean distance of Jupiter from the sun is 483,000,000 miles; but as its orbit has a certain eccentricity, its distance from the sun varies from 462,000,000 miles at the nearest point to 504,000,000 miles at the farthest point. The orbit of Jupiter is only very slightly inclined to the ecliptic, the inclination being 1° 19′. Owing to the movement of the earth round the sun, Jupiter appears, at intervals of about a year and a month, to stand still in its journey through the starry heavens, and even to retrace its steps for some distance, before going on again along the course which it takes nearly 12 years to accomplish.

In strong contrast to the long period of its orbital revolutions, Jupiter rotates on its own axis with stupendous velocity, so that its day, corresponding to ours of twenty-four hours, is completed in about nine hours and fifty-four minutes, giving to every point on its surface about five hours from sunrise to sunset and five from sunset to sunrise.

The different paces of the planet's different envelopes

But this planet, or at any rate its visible surface, does not rotate all as one solid body. Jupiter is in this respect, as in others, like the sun. The equatorial regions travel round more quickly than the regions of higher latitude, the former completing the circuit of day and night in nine hours and fifty minutes, while the parts which are nearer the pole take seven minutes longer to perform the same circuit. Moreover, different spots in the same latitudes travel with somewhat different speeds, and even the same marking has been observed with great exactness to vary from time to time the rapidity of its rotation. All these facts show that what we see of Jupiter is not a solid crust, like the earth's, and, indeed, it is very doubtful whether Jupiter has any solid body at all. The axis about which it rotates is very nearly vertical to the plane of its orbit, being inclined to it by only three degrees. There are, therefore, no well marked seasons; but Jupiter seems to be still, as regards heat, in the self-sustained

stage, and hence the sun's effect being excluded from its surface there would be no seasons even if its axis were much more inclined, like the axis of the earth.

The four larger satellites the first discovery of Galileo's telescope

Jupiter has no fewer than twelve moons, which circle around it. Eight of them are of very recent discovery, but the four larger satellites were the first objects to be discovered after the invention of the telescope. It was on January 7, 1610, that Galileo turned his new instrument upon the giant planet, and saw that it was attended by four little stars which moved to one side of the planet and then to the other side, and passed before and behind it, giving the impression of a solar system in miniature. Galileo named them the "Medicean stars", after his patron, Cosmo de Medici. Nearly three centuries were to elapse before the smaller satellites would be discovered, as it was not until 1892 that the fifth moon was found by the late Professor Barnard, at the Lick Observatory.

The moons and recently found moonlets of the giant planet

The four moons discovered by Galileo were named, in order of their nearness to the planet, Io, Europa, Ganymede and Callisto. In size the two inner ones, Io and Europa, are not very different from our own moon, but Ganymede and Callisto are over twice that size. Their distances from Jupiter are respectively 261,000 miles, 415,000 miles, 664,000 miles and 1,167,000 miles. Taking them in the same order, the periods of their revolutions, reckoned in days of Jupiter, are about $4\frac{1}{4}$, $17\frac{1}{4}$, $8\frac{1}{2}$ and $40\frac{1}{2}$ days.

Although these four greater moons would be of considerable size from the terrestrial point of view, they are very minute as compared with the planet to which they belong. Ganymede, for instance, has nearly twice the volume of the planet Mercury, and about two-thirds of the volume of the planet Mars, yet the volume of the four major satellites put together is little more than one-8000th of the volume of the giant Jupiter.

The orbits and occultations of Jupiter's little retinue of moons

The orbits in which the satellites move are in the plane of the equator of Jupiter, which is also the plane of the ecliptic or orbit of the earth's. They appear, therefore, as tiny stars lying along a horizontal line which passes through the center of the planet; and the system of Jupiter and the four moons of Galileo cover a space in the sky about equal to two-thirds of the apparent diameter of our moon. These moons may be seen in transit over the face of Jupiter, and disappear, or are occulted, when they pass behind its disc. They are eclipsed when they pass into the huge shadow which extends outward from the planet away from the sun; and from the fact that they become invisible when eclipsed it is unlikely that Jupiter, as some have supposed, throws out any light of its own. Further, they eclipse their own planet, and may be seen to do so. Not that their tiny forms can throw the giant planet into darkness, but their shadows can be seen traveling over its disc as minute black spots. From time to time it happens that all four become invisible simultaneously, some being eclipsed, and others being occulted or in transit over the planet's face.

These moons, like Jupiter itself, receive, area for area, only one-twenty-seventh of the sunlight which is received on earth, and therefore cannot have much importance as luminaries. Otherwise, they appear to be more efficient reflectors than our moon, except Callisto, which is curiously dark.

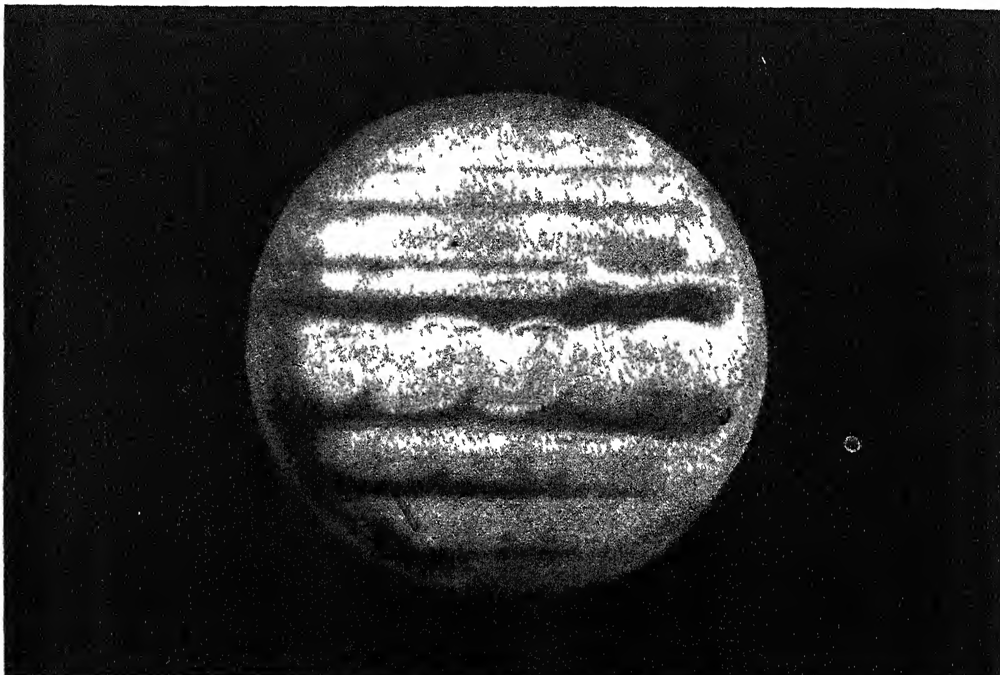
The puzzling variation in the light of Jupiter's moons

The four moons not only differ considerably among themselves in brightness, but, they vary also individually from time to time in the amount of light which they reflect. There are regular and also irregular variations. Callisto appears to change in reflective power according to the position which it holds in its orbit, and is therefore believed to turn as our moon does, keeping always one face to its planet, and so turning surfaces of different

degrees of whiteness and blackness in regular alternation towards the sun. The very puzzling irregular variations in luminosity have been noticed by many astronomers since Galileo, and admit of little doubt, although some of the most skilful observers with photometric instruments have failed to obtain reliable evidence of irregular changes in brilliancy.

Definite markings have been made out, by telescopes of high power, upon the four greater satellites of Jupiter. Those upon the surface of Ganymede are specially interesting, it being claimed that they resemble the canal markings upon the planet Mars. Areas of great brilliancy, supposed to be ice-caps, have been distinguished upon Callisto and Ganymede. Io, the innermost of the four, has in general a fairly dull surface, but has a broad zone of light color round its equator. These moons are, however, at so great a distance from the earth that only the largest markings upon them can be made out at all, and even these not with great certainty.

From 1610 until 1892, only these four moons were known, but since then their number has been tripled. In September 1892, the late Professor Barnard, at Lick Observatory, discovered a fifth very small moon, having a diameter of only about 100 miles, revolving very close to Jupiter within the orbit of Io, and completing its orbit in somewhat less than 12 hours. This satellite, from its proximity to the brilliant planet, is extremely difficult to observe. A few years later, in December 1904 and January 1905, Professor Perrine, at the same observatory, discovered by means of photography two minute satellites even smaller than that of Barnard, and moving in orbits outside those of Galileo's moons. Three years later, in 1908, Mr. Melotte, of Greenwich Observatory, discovered by photography an eighth satellite, very small, very distant from Jupiter, and moving in an extremely eccentric orbit. But the most remarkable quality of this eighth satellite is that it is retrograde — that is to say, it revolves in the contrary direction to the revolution of the others. Then in 1914 Nicholson discovered photographically at the Lick Observatory the ninth satellite which is also retrograde.



JUPITER, SHOWING ITS BELTS OF CLOUDS, THE OVAL RED SPOT ABOUT 1880, AND A SATELLITE WITH THE SHADOW THAT IT CASTS ON THE PLANET

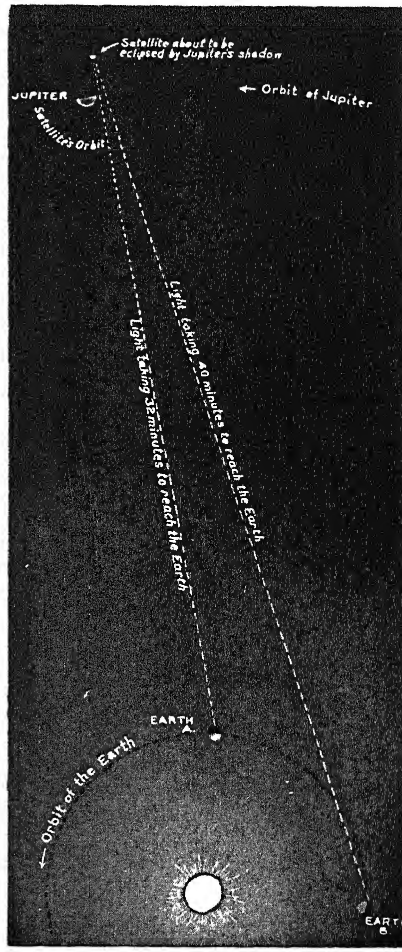
This retrograde movement is of great importance, because of the far-reaching theories that have been based upon it.

Late in 1938 the Carnegie Institution of Washington announced that Dr. Nicholson, using Mt. Wilson's 100-inch telescope, had discovered two more moons, thus bringing the total of Jupiter's known satellites to eleven. In 1952 the institution announced that Dr. Nicholson had discovered a twelfth moon of Jupiter.

We must not leave the subject of Jupiter's satellites without referring to the very interesting way in which their movements were formerly made to give evidence with regard to the speed of light. There are now more exact ways of determining the velocity of light by laboratory experiments, but the eclipses of Jupiter's moons were the phenomena which first showed that light travels at a speed of some 186,000 miles in a second.

Roemer, a Danish astronomer, was the first, in 1675, to explain a remarkable fact with regard to these eclipses. The orbits and velocities of Galileo's moons being known with great exactness, it was possible to predict the moments at which eclipses, transits and occultations of these moons ought to take place. It was found, however, that in proportion as Jupiter, in the course of its orbital motion, departed further from the earth, in the same proportion the eclipses, transits and occultations of Jupiter's moons were retarded beyond the times at which it had been calculated that they ought to occur. On the other hand, the gradual approach of Jupiter towards the earth was accompanied by a gradual return to punctuality of these eclipses and other phenomena. So vast is the range of the planet's movements that when it is farthest from us the eclipses as observed by us are more than 16 minutes behind their time. Roemer saw that these changes were perfectly intelligible if light, instead of being an instantaneous flash, were a movement of great velocity, yet still taking some appreciable and measurable time to accomplish a given distance. He proved his case beyond question, yet his conclusions were rejected until many years after his death.

The surface of Jupiter is an extremely good reflector, returning over 60 per cent of the light which it receives. Like that of the sun, Jupiter's disc is brightest towards the center, and darkest towards the edge, whereas the terrestrial planets — Mercury, Venus and Mars — are apparently brighter towards the edge than in the center. Whether this quality, in which Jupiter resembles the sun, is due to its light being partially its own glow and only partially reflected sunlight, is a difficult question. The giant planet does appear to glow, but the light thus produced



HOW THE VELOCITY OF LIGHT WAS FIRST DISCOVERED

By observing the phenomena of Jupiter's satellites Roemer noticed that anticipated eclipses did not occur to time, but that when the earth was at *B*, for instance, the eclipse was eight minutes later than when at *A*, or nearly 100 million miles nearer to Jupiter. This diagram also shows the relative distances of the earth and Jupiter from the sun.

does not amount to much, because it is insufficient to light up the moons when they are eclipsed. Professor Young suggested that a nearly transparent atmosphere overlying a uniformly reflecting surface would produce this effect of a darkened edge.

The beautiful spectacle of form and color which is Jupiter, the giant planet

When seen through a powerful telescope, Jupiter becomes a beautiful spectacle of form and color. It is obvious at once that we are not looking upon the face of a solid world, but upon an immense ocean of cloud, with visions of a glowing interior of dusky cherry-red. Brown, maroon, dark green and purple colors diversify the picture. The markings are inconstant, and shift their places and relations, leading us to conclude that they are only cloud forms, but, on the other hand, considering that they are nothing more substantial than clouds, they have extraordinary stability. The main structure of the markings consists in belts parallel to the equator; but as these are whirled round before the eye in the swift rotation of the planet, they are seen to be irregular and shifting. The entire scene suggests clouds at the first glance; the wavy, streaky alternations of dark and light, lying in the horizontal direction, are like the stratified clouds often seen in the west at sunset. The most constant features are two broad bands of dark color, one on each side of the equator, in the position of the terrestrial belts of trade wind. The brilliantly reflecting bands of light color, lying between and north and south of the darker zones, are certainly clouds, reflecting light in exactly the proportion in which our clouds do.

Whether, as is most probable, they are clouds of water droplets, or, as they may well be, clouds of some other kind, has not yet been determined. But we know that they are produced by vapor distilled from Jupiter's surface by its own heat, and condensed into droplets by the chill of outer space. They are not produced, as our clouds are, by evaporation through the sun's heat, because no change is caused in them by the diurnal rotation of the planet. When they come round its edge, they reappear at sunrise just as they passed from our view at sunset. Night and day make no difference to them. The lapse of time makes no difference to them. Particular markings may last for a day or for a generation.

Examination of the light and dark bands by means of the spectroscope has shown that the light from the dark bands has passed through a deeper layer of the atmosphere than has the light from the bright bands. The reflecting surface, which we see in the dark parts, is therefore at a lower level on the planet than that of the bright white clouds. The general arrangement of the markings in horizontal lines is believed to be due to winds set up by the velocity of the planet's rotation on its axis; and the violence of these winds, if such they be, may be judged from the fact that the linear velocity of the faster moving belts is about 200 miles an hour greater than that of the more slowly moving ones.

One of Jupiter's markings has received great attention, and has thrown much light on its structure. In shape very much like an airship, situated horizontally in a band of bright clouds, the area known as the "great red spot" was first observed in 1878, when it was of a faint rose color, and was about 30,000 miles long, with a breadth of about 7000 miles. Within a year it had grown enormously in size and tint, stretching across about a third of the planet's disc, and having a bright, almost vermilion color. Four years after its first appearance it began to fade, and in subsequent years changed into a faintly colored ring, grew again in strength of color and definition, and has undergone many variations until the present day. The great red spot is passing away, and has never regained anything like the development which it had in 1880.

Its character has provoked endless speculation. In 1891 it was slowly pursued for several months by a small dark spot, which ultimately overtook it, and was then shattered. The great red spot was probably volcanic in nature. It is seen in the illustration on page 3088.

STARCHES AND SUGARS

Widely Distributed and Comparatively
Cheap Sources of Food Material

WHAT THE CARBOHYDRATES HAVE TO OFFER

STARCHES and sugars belong to the group of foodstuffs known as "carbohydrates". These compounds are made up of the chemical elements carbon, hydrogen and oxygen, the hydrogen and oxygen being in the same proportion as in water, the ending of the name being derived from the Greek word meaning water. The starches and sugars are widely distributed in the vegetable kingdom, affording a comparatively cheap source of food material. Nature always practises true conservation. Animals breathe out a waste product, carbon dioxide gas, which is absorbed through pores in the under surface of the leaves and made use of in a most interesting and efficient manner. In the tiny leaf-laboratory through the agency of chlorophyll cells (those containing the green coloring matter), sunlight and water, a new substance is formed — starch.

For convenience in discussion, the carbohydrates may be simply grouped as follows: (*a*) cellulose, (*b*) starches, glycogen and dextrin, (*c*) sugars.

Cellulose is a fibrous material which forms the skeletal framework of all plants and corresponds to the bony material of the animal body. Although a carbohydrate containing the same chemical elements as starch and sugar, cellulose is not important as a fuel food for the human organism, since it is not affected by the ordinary processes of digestion except when acted upon by fermentative bacteria. However, many of the lower animals possess digestive enzymes which dissolve cellulose and the products are absorbed. In this way, hay and many tough plant tissues are utilized by animals whereas we must have more delicate food material. The important function of cellulose is not that of supplying actual food but rather consists in adding bulk to otherwise concentrated dietaries, and the consequent stimulation of intestinal peristalsis. In discussions of digestion this material is spoken of as "roughage".

Starch is the most abundant of the nutritive carbohydrates and represents a very important source of food. Its chemical formula is $(C_6H_{10}O_5)_x$. The more important carbohydrates contain six atoms of carbon or multiples of six in the molecule. Starch is very complex and contains many times six carbon atoms, which fact is represented by x outside the bracket in the formula. It occurs in all parts of the plant with the exception of the tips of the buds and the rootlets. The largest quantity is, however, in the storage organs of the plant such as roots, tubers and seeds; and sometimes in the fruit, as in the banana. This store of carbohydrate is the reserve nutriment for the development of the young plant. Starch occurs as a glistening white powder, the size and shape of the granules depending upon the particular plant which produces them (see Figure 1). A microscopic examination of starch granules reveals certain common characteristics. The starch appears to have been deposited in layers around a central point and the outside case or envelope is of a hard material, insoluble in cold water. This is called "starch-cellulose" and is believed to have been formed in the plant from starch.

Raw starch is insoluble in cold water but under the influence of heat, it takes up water, swells and becomes semi-transparent, forming an opaque solution. This is not a true solution but a colloidal one. The absorption of water causes the starch grain to swell and burst with the liberation of pure starch. This is the important factor in the thorough cooking of cereals and potatoes. The common test for starch is with iodine, in contact with which the outer walls of the granule turn a dingy yellow, while the interior becomes deep blue. There is no other known substance which gives this color test.

In digestion, starch is changed by the action of enzymes from a complex substance to much simpler ones. All digestible starches are changed to sugars before they can be absorbed from the digestive tract. Starch takes up water chemically, forming first dextrin, then maltose and finally glucose (dextrose). This change may also be brought about outside the body by heating in the presence of dilute acids.

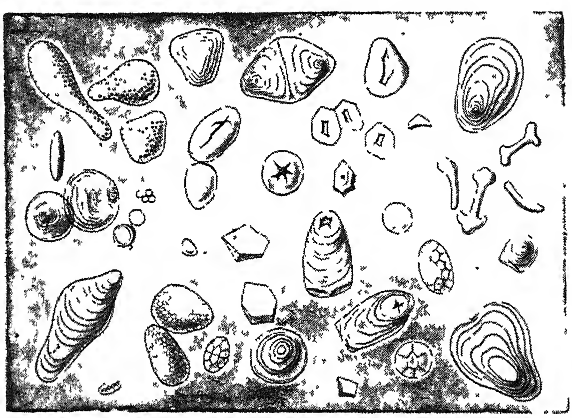


FIG. I.—VARIOUS FORMS OF STARCH GRANULES

Glycogen, sometimes called "animal starch", is almost identical with vegetable starch and small amounts are found in the liver and traces in the muscle cells of animals. Glycogen is changed to glucose as it is needed in the blood. It gives a reddish color when brought into contact with iodine.

Dextrin is an intermediate product in the formation of sugar from starch. It is well known as the sweetish, glossy coating on the crust of a loaf of bread or in well-browned toast. Commercial dextrin or "British gum" is usually seen as a brownish powder with a mealy odor. It is also produced in a granular form as semi-transparent lumps, resembling gum arabic, for which it is a cheap substitute. It forms a viscous solution with cold water and is used for gumming labels, envelopes, etc., for finishing cloth and as a thickening for mordants in calico-printing. Dextrins are manufactured by heating starch, either alone or after treatment with acid, at a temperature of 338° to 536° F.; this is from 126 to 224 degrees higher than the boiling point of water.

Starch is prepared on an industrial scale from the parts of various plants which contain it in abundance. The successful manufacture depends upon the absence of much protein and gummy material which make the extraction difficult and expensive. In very early times wheat was the main source of starch, but now many other sources have been discovered. Early in the eighteenth century the potato began to be used to a great extent in Europe and in the United States, as a cheap source, yielding more starch per acre than grain, notwithstanding the fact that wheat and rice contain an average of from 70 to 75 per cent, while potatoes, as marketed, contain only about 15 per cent. If a potato is pared and grated, washed with water and the cellulose then strained out, a milky fluid is obtained and if this is allowed to stand a layer of starch will settle to the bottom of the vessel. The water may be decanted and the starch further washed, purified and dried for use. Many of our grandmothers prepared starch in this way for laundry purposes. This grating of the material, washing out of the starch granules and allowing them to settle shows the principle of starch manufacture, although, needless to say, some machinery is required for commercial preparation. During the settling process a weak solution of sulphurous acid is often added to prevent souring.

Commercial preparation of starches and principles involved in their cooking

The starch from corn is also used extensively, and corn products represent a very important industry in the United States. The grain is soaked to soften it and then the bran and germ are removed. It is then cracked, ground and washed with water to remove the starch granules. Nothing is wasted, the germ and bran being used as fodder. The oil is well known as "Mazola" oil and is used for many purposes. Glucose is also an important product manufactured from corn and will be discussed under sugars.

The cassava is one of the tropical rivals of the potato and furnishes tapioca for the people of the temperate zone. It has a long, slim root and is used in Brazil, Guiana, the West Indies, West Africa, the East Indian Islands and the Malay Peninsula. In these countries cassava cakes replace corn bread and other cereal products. The cassava is ground and washed in much the same way as the potato to remove the starch.

In the West Indies the roots of the *Maranta arundinacea* are utilized for the preparation of arrowroot, a very fine grade of starch.

Sago is obtained from the pith of the sago and other palms. The palms are cut into lengths, split, and the pith removed, and from it the starch is prepared. Large quantities are exported from Singapore.

The principles involved in cooking starch-rich foods depend upon rupturing the cellular envelope of the granule as already discussed. It is necessary that the envelope be ruptured in order to liberate the pure starch so that the digestive juices may come in contact with it. This is best accomplished by thorough cooking with water — the water softens the cellulose, gradually penetrates the granule, causing it to swell and burst. In some foods there is enough water present to soften the cell walls, as is exemplified in the baking of a potato. A temperature higher than that of boiling water will make starch digestible even if dry heat is applied, as in the case of the formation of dextrin.

The second great class of carbohydrates: the sugars

Sugars, the second great class of carbohydrates, are characterized by their sweet taste. There are a great many sugars, but generally speaking the term "sugar" has reference to sucrose obtained from the juice of the sugar-cane, sugar-beet and maple tree. In earliest times the only sweetening agent used by man was honey produced by wild bees. The food sugars are classified as follows:

1. Double sugars, technically called "disaccharids". This group includes (*a*) sucrose or cane sugar; (*b*) lactose — the sugar in milk; (*c*) maltose — the sugar that is found in sprouted barley or other germinating seeds.

The chemical formula for the sugars of this group is $C_{12}H_{22}O_{11}$. Although the empirical chemical formula for these three sugars is the same, there are differences in their behavior as to solubility, formation of crystals, etc. by which means one may be distinguished from another.

2. Simple sugars or "monosaccharids". This group includes (*a*) glucose or dextrose; (*b*) fructose or levulose; (*c*) galactose. The chemical formula for this group is $C_6H_{12}O_6$. They are the simplest sugars which exist as such, for if broken down further they lose their sweet taste and other sugar characteristics.

It may be observed that while the molecule of a disaccharid sugar contains twelve atoms of carbon, that of a monosaccharid contains only six. Under certain conditions the double sugars or disaccharids are split, forming simple or monosaccharid sugars. This change may be brought about in cookery or in commercial processes by heating the sugars in the presence of dilute acids when the double sugar takes up water chemically, or, in other words, is *hydrolized*, forming simple sugars. The same change occurs in the body during digestion when double sugars are acted upon by the sugar-splitting enzymes. Sucrose or cane sugar is split, forming glucose and levulose; lactose forms glucose and galactose; while maltose forms two molecules of glucose.

Sucrose is the sweetest of the sugars, having twice the sweetening power of glucose. There has been great rivalry between the cane and beet as sources of sucrose but we find when purified they are of equal value.

Lactose, or milk sugar, occurs in milk. It is not so readily soluble in water as sucrose and is not nearly so sweet. It does not ferment easily so is particularly valuable for infant feeding, and for invalids. Its lack of sweetness enables them to take large quantities, thus increasing the total calories in their diet.

Maltose, which is the typical sugar found in malt, is produced in the sprouting of barley when some of the starch is changed to maltose. At this stage the process is stopped by heating and a large amount of malt sugar is obtained. This serves as food for the yeast plant, which in feeding upon it produces carbon dioxide gas (the bubbles seen in fermenting substances) and alcohol. This is the principle of all sugar fermentation. The sugar is broken down into simpler substances which are no longer sugar. Thus the sweet taste disappears and the nippy flavor of alcohol remains.

Glucose and fructose occur in many fruits and vegetables, as grapes, cherries, bananas and carrots, the quantities varying with the ripeness of the fruit. However, glucose is seldom prepared from fruit juices in commerce as it can be made with less expense by the hydrolysis of starch which is broken down into its component sugars. The old fear of using glucose, owing to the acid required in hydrolysis and possible traces of arsenic, has been abolished with improved methods. Glucose is less easily dissolved than cane sugar and does not crystallize so readily.

Fructose (fruit sugar), or levulose, is found in many fruits. It is very easily fermented by yeast and has a very sweet taste. It is frequently added to wine and beer to aid fermentation. The chief sugar in honey is invert sugar — a mixture of glucose and fructose.

Galactose is not found free in nature but is one of the simple sugars formed in the splitting of lactose or milk sugar.

Minor sources of sugar: from tree sap, from coal-tar, from sorghum

There are several minor sources of sugar which are not so important commercially as those already discussed.

Maple sugar is produced by the evaporation of the sap from the sugar maple. A small hole is bored in the tree and a tiny trough or spout placed in the opening and the sap drips into a pail below. When prepared on a small scale, the sap is usually boiled in large open kettles in the woods and poured into molds to crystallize. Instead of boiling to sugar the product is sometimes used in a more dilute form as the much relished maple syrup. This sugar is sucrose but costs much more than cane or beet-sugar. It is liked on account of the peculiar flavor of the crude product and is consequently not refined. Climatic conditions affect the flow of the sap and the geographical area which suits the sugar-maple is limited. The production of maple sugar is particularly important in the Green Mountain region of Vermont, the White Mountain region of New Hampshire and the adjacent parts of Canada.

Sorghum is derived from a plant which resembles a stalk of corn and is grown in the central part of the United States for the making of syrup for local use. At present its sugar content has not been improved as has that of the sugar-beet, but no doubt it may become a very important source of sugar in the future, since it can be cultivated with work animals and machines rather than by hand labor.

Saccharin is not a sugar, although it is a substance which is from three to four hundred times as sweet as cane sugar. It is a coal-tar product which has no food value and is frequently used for sweetening food for diabetics who are not usually allowed to eat sugar. It has not been definitely determined whether saccharin has any injurious effect on the system, but at any rate when it is used in drinks like sodas, phosphates, etc., and to sweeten syrups, there is harm in fooling the public who may believe they are getting a food sugar. Consequently the use of saccharin is being discouraged.

The effect of heat on sugar

The cooking of sugar solutions is found difficult by many people unless they have had much experience in making candies and icings. There are only a few principles based on chemical behavior which affect the cooking of sugar. When sugar is heated dry, it gives off water of crystallization and melts, forming first a clear mass which hardens on cooling and is called "barley sugar". If heating is continued, further changes take place, and at about 350° F. caramel is formed. The mass froths up and if desired for flavoring it should be removed from the heat. On cooling, a brownish non-crystalline product is obtained and may be dissolved as needed; or instead of removing from the fire, a little boiling water may be added to form a heavy syrup, which keeps well. If the product is desired for coloring it may be heated to 380° F., and must be removed from the heat immediately to prevent charring This dark brown material, which on cooling becomes a hard brittle mass, is used to color gravies, vinegar, beer, etc. It is soluble in water, has a bitter taste, is not fermented by yeast and melts at about 275° F.

When cane sugar is dissolved in water and boiled, the added water is gradually driven off, the temperature of the sugar solution rises and we obtain the density or concentration required for various confections. Thus a thermometer indicates the concentration of the syrup and is most useful, and surer than one's judgment, which must depend upon experience. It is well known that a concentrated solution of a substance is inclined to form crystals around other crystals. This is made use of by sugar manufacturers in the "graining" of syrups by throwing a few sugar crystals into the mass of hot syrup to start the crystallization. So in cooking sugar, when crystallization is not desired, the crystals from the sides of the saucepan and from all utensils must be washed off. Stirring or jarring while hot will tend to cause a concentrated solution to grain; thus a boiling syrup should be cooled before disturbing or stirring it.

Glucose does not crystallize as readily as sucrose, consequently a small portion of it is frequently used with cane sugar when a creamy mixture is desired Similar results may be obtained by adding a small quantity of acid when heating the sugar in order to change a little of the sucrose to glucose. This is the reason for using lemon juice or a pinch of cream of tartar in fondant. Glucose and syrups are used to a large extent in commercial candy-making.

The approximate temperatures for the heating of sugar solutions for various purposes are as follows — for fondant, fudge and similar candies from 235° to 240° F.· for taffy and candies to be pulled, 300° F. for clear brittles, 310° F.

Starches and sugars as sources of fuel

The fact that the body requires food for various purposes has been discussed. Since the largest amount of food is required to supply fuel to keep up the normal temperature of the body and to supply energy to carry on work, carbohydrates are very important. The best commercial fuels are those containing carbon, for example — wood (cellulose), coal, kerosene; these are burned, producing carbon dioxide gas and water; and in most cases there are some incombustible materials or ash. In the body, although the burning takes place at a much lower temperature, the fuel is burned and produces the same end products. If the food contains mineral matter such as lime or iron, there is an ash remaining in the body. These mineral constituents are necessary, however, for the building of all body tissues. The purified carbohydrates such as starches and sugars have practically no ash so that the material absorbed from the digestive tract is completely consumed. It may be seen, therefore, that these are a very good source of fuel with little waste.

The digestion of starches and sugars

Starches digest more quickly if cooked in order to burst the cellulose envelopes of the granules so that the digestive enzymes can get at the pure starch. Thus the cooking of all starch-

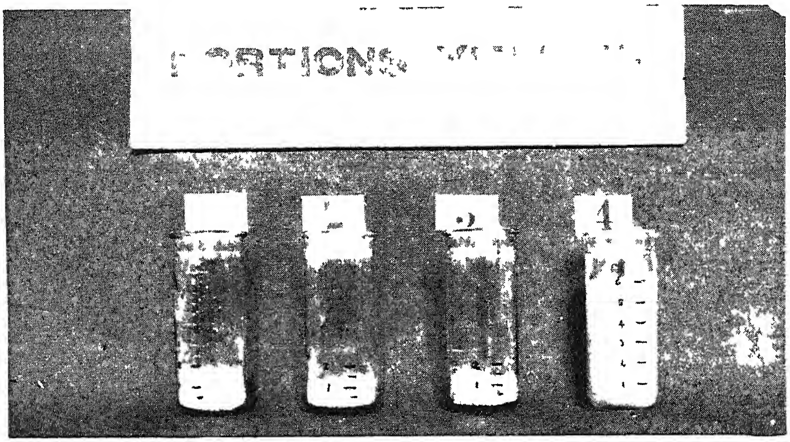


FIG 2. — 100-CALORIE PORTIONS OF STARCH

1 Corn-starch, 2 sago, 3 tapioca; 4 tapioca (cooked). All are in 8-oz jars

rich foods is important. In the body, starch undergoes a process of hydrolysis similar to that which takes place on heating in the presence of dilute acids. A digestive enzyme acting upon starch is present in saliva, changing it first to dextrin and then maltose if sufficiently masticated. Traces of glucose may be formed. The digestive juice of the stomach contains no specific enzyme which acts on starch but if the saliva has been well mixed with the food, its action may continue for some time after the food enters the stomach or until its activity is inhibited by contact with the gastric juice. There is probably very little of the final product glucose produced before the starch reaches the small intestine, where that which has escaped digestion is acted upon by enzymes found in this part of the digestive tract. Glucose is formed and absorbed into the blood, and any surplus is stored as glycogen in the liver. This supply is drawn upon as needed to keep up the small percentage which the blood is constantly carrying to the tissues to be burned. From ten to fifteen ounces of glycogen may be stored by the average adult. Any surplus beyond this amount is used to form fat which is the chief reserve fuel of the animal organism. The double sugars, sucrose, lactose and maltose are split by enzymes in the small intestine to simple sugars which are absorbed. There is no appreciable change in the sugars in the mouth and stomach. Bacteria may cause the sugars to ferment in the digestive tract, producing gas and unpleasant results. The simple sugars do not have to undergo digestion so are very quickly absorbed and utilized. In the case of all the sugars the process is rapid so that they furnish a valuable fuel when energy is required immediately Consequently sugar-rich foods are frequently used by soldiers on the march or by those subjected to strenuous exertion for a short period. Sugar is not essential, however, and may be replaced by starch, wholly or in part, without lowering the fuel value of the diet. If large quantities of sugar are eaten at one time the membrane of the stomach is likely to become irritated and nausea frequently results. This is one reason for giving children very small quantities of candy at a time.

As has been previously stated the fuel value of food means its heat value, which is measured by calories. The starches and sugars with their high fuel value are deficient in protein, mineral constituents and vitamins.

In figures 2 and 3 are shown 100-Calorie portions of some of the starches and sugars. It requires about two level tablespoons of granulated sugar, molasses, honey or maple syrup to produce 100 calories. The bulk of a similar portion of brown sugar is about two-thirds as much again as that of cane sugar. To yield 100 calories practically the same amounts of raw sago and tapioca are required as of cane sugar. When

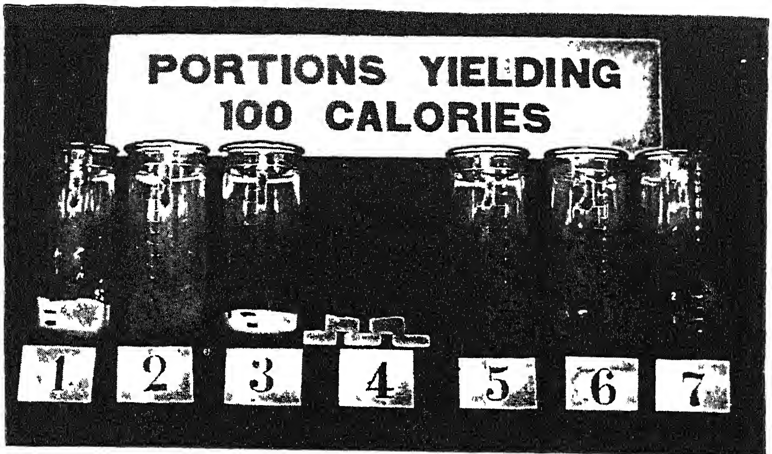


FIG. 3 — 100-CALORIE PORTIONS OF SUGAR AND SYRUPS
1. Milk-sugar; 2 brown sugar; 3 granulated sugar, 4 loaf sugar; 5 honey, 6 corn syrup; 7 molasses All are in 8-oz jars

cooked, however, these materials increase in bulk, as is shown in figure 2. The volume of cooked tapioca is from four and one-half to five times as great as that of the raw. It has been stated authoritatively that for every 100-Calorie portion of food required we should have 0.023 grams of calcium and 0.5 milligrams of iron. Ordinary granulated sugar and brown sugar do not contain mineral constituents, but molasses, honey and maple syrup yield appreciable amounts: molasses 0.074 grams of calcium and 2.55 milligrams of iron; maple syrup 0.037 grams of calcium and 1 milligram of iron; honey 0.002 grams of calcium and 0.3 milligrams of iron. As a 100-Calorie portion of these sweets may easily be eaten at one time, it is readily seen that molasses may be used to increase the calcium and iron content of the diet. Calcium is particularly necessary for children and the best source is milk, but if for any reason the amount of milk taken by children is too small to supply the necessary calcium, the use of molasses in cookies, candies, etc. is worth considering. There are many foods which are deficient in calcium and iron so that we cannot afford to disregard any source of these important constituents of the dietary. In a well-balanced diet from 35 to 50 per cent of the total calories may come from starch-rich foods, and from 10 to 15 per cent from the sugar-rich ones. If more than this allowance of sweets is used there are apt to be digestive disturbances and a lack of appetite for other foods — thus the supply of adequate protein, vitamins and mineral matter may reach a dangerous minimum.

Photo Elmendorf © Ewing Galloway, N Y.

NIAGARA FALLS AND RAPIDS UNDER A CLOUDY SKY

The condensation of the water-vapor in the atmosphere makes clouds from which comes rain. They hold latent in their fleecy bosoms all the rivers of the world.

PROBLEMS OF CLOUDLAND

The Many Meanings of the Kaleidoscope of the Sky, and what Its Changes do for Man

THE BATTLE BETWEEN EARTH AND SUN

AS we have previously stated, the atmosphere always contains a certain amount of water-vapor; and when the amount reaches saturation-point the vapor condenses on cold, solid bodies such as dust or leaves, and forms clouds, mist, fog, rain and dew. These are all akin They are all beads of condensed water-vapor, and the difference between them is chiefly a matter of size and position When the drops are high in the air and are of such small size that gravity hardly affects them, a cloud is formed. Near the ground they make a fog or mist When drops of various sizes are condensed directly on leaves and stones they are called dew. And when drops are of considerable size, and fall comparatively rapidly through the air, we have rain. But there is no hard and scientific division between these forms and conditions of condensed water-vapor. What seems a cloud on a hilltop when we see it from the plain will seem a mist if we are on the hilltop and enveloped in it Still, in a rough way, the several terms indicate several types, and in this chapter we shall separately consider clouds in their typical aspect as condensed water-vapor.

No natural phenomena make a greater appeal to poetry and art than the clouds. They are the mingled banners and meeting oriflammes of the empery of the sun, and of the puissance of the earth. Under their streamers is fought a mighty battle between heat, and cold, and gravitation. Nor in all nature is there a combat with consequences more momentous It is a life and death battle. Did the sun win, earth would become a desert. Did the sun retire from the unequal contest, all land life would end; there would be no more falling rain, no more rippling rivers, nothing but a brimming sea Even in the sea life would suffer, for the lime salts would soon be used up, and would no longer be replenished from the land But the even and recurrent battle means salvation to man, and signifies that all goes well with the world

Regarded under a less martial metaphor, the clouds represent the weights of a wound-up clock; they represent weight lifted by the sun, and the lifted weight represents potential energy But what a clock it is, and what enormous energy the clouds contain! They hold all the rivers in the world Latent in them are the Congo, the Mississippi, the Amazon, Niagara, the Victoria Falls It is these airy, white, floating clouds that grind down the mountains, that hollow out the valleys, that cut the canyons; it is these white clouds that laid down the mud of the deltas and added Egypt and the Netherlands to the map of the world Were the water not lifted by the sun, it would be futile and impotent; and equally futile and impotent would it be were it not condensed by the cold and caught back to the bosom of Mother Earth The height of the clouds is a measure of the work-capacity of the water they hold; and small and dispersed though the drops of water in a cloud may be, yet the aggregate weight of the water-drops must in some cases be enormous

Regarded in yet another light, clouds are bearers of heat—giving off energy in that form. For every ounce of water-vapor as it condenses gives forth a definite quantity of the latent heat which maintained it in a gaseous condition; and the total amount given off during the process of condensation of a cloud is very large.

The artistic inspiration that has had its origin in the glories of cloudland

Regarded artistically, clouds are as suggestive and inspiring as mountains or the sea, and literature is full of fine passages they have inspired. Listen to Ruskin: "And yonder filmy crescent, bent like an archer's bow above the snowy summit, the highest of all the hills — the white arch which never forms but over the supreme crest — how is it stayed there, repelled apparently from the snow — nowhere touching it — the clear sky seen between it and the mountain edge, yet never leaving it — poised as a white bird hovers over its nest? Or those war-clouds that gather on the horizon, dragon-crested, tongued with fire, how is their barbed strength bridled? What bits are these they are champing with their vaporous lips, flinging off flakes of black foam? Leagued leviathans of the Sea of Heaven, out of their nostrils goeth smoke, and their eyes are like the eyelids of the morning. The sword of him that layeth at them cannot hold the spear, the dart, nor the habergeon Where ride the captains of their armies? Where are set the measures of their march? Fierce murmurers answering each other from morning until evening — what rebuke is this which has awed them into peace? What hand has reined them back by the way by which they came?"

In this fine passage, Ruskin commences a discussion of the reason why clouds float; and he comes to the conclusion that we do not know what makes clouds float, but that "it is conceivable that minute spherical globules might be formed of water, in which the inclosed vacuity just balanced the weight of the inclosing water, and that the arched sphere formed by the watery film was strong enough to prevent the pressure of the atmosphere from breaking it in. Such a globule would float like a balloon at the height in the atmosphere where the equipoise between the vacuum it inclosed and its own excess of weight above that of the air was exact. It would probably approach its companion globules by reciprocal attraction, and form aggregations which might be visible."

The place of clouds that are always dropping taken by clouds nearly formed

Some such theory as this was held by meteorologists for some time, but now the reason *is* known why clouds float, and it is that they do not really float at all, any more than a rainbow floats. The drops of water in a cloud are not balloons, but parachutes; they are always dropping, as their name implies. They fall, it is true, very, very slowly, but still they fall, just as the larger raindrops do. The clouds may be blown by the wind up and down, but individual water-drops cannot escape the law of gravitation, and must fall

How, then, have clouds such permanency of shape? The shape of a cloud is essentially the shape of the area of condensation, and the general shape is preserved for a time, though the constituent particles are falling, simply because, as condensed drops fall as rain, other small particles are condensed in the area of condensation to take their place.

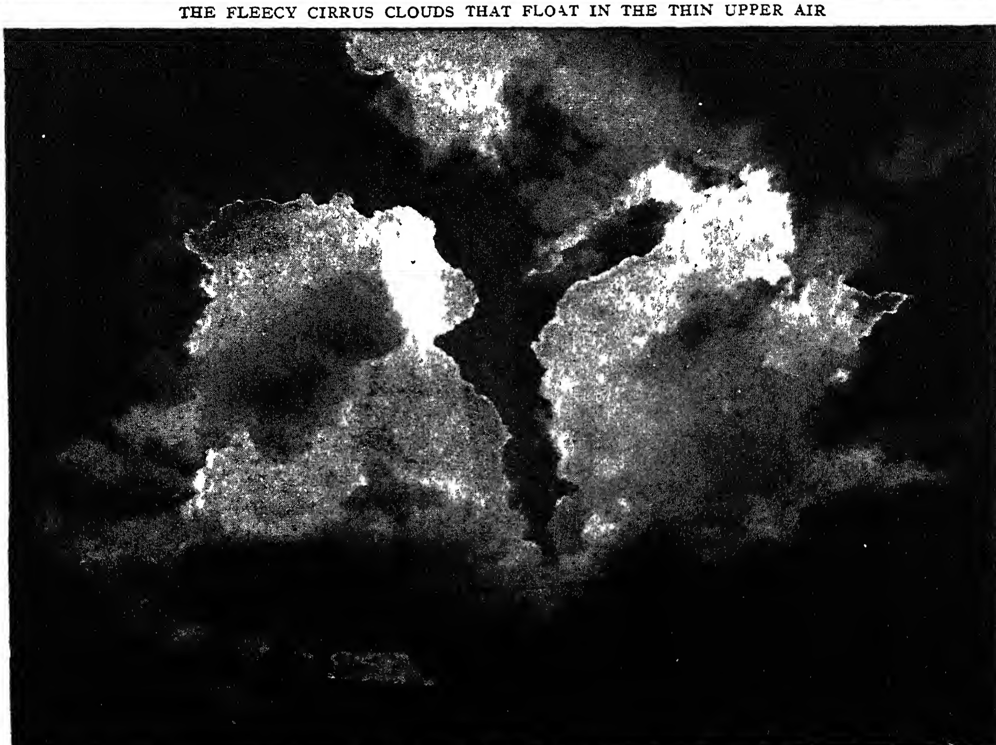
Dust the scaffolding upon which the clouds are built

This permanency of shape with fluctuation of constituent water-drops is well seen in the famous "Tablecloth" that hangs over the edge of Table Mountain, in Cape Colony, Africa The lower fringed edge of the cloud is usually dripping rain, and yet it will keep its shape and size for days, simply because a warm, wet wind is giving up its moisture to the cold mountain.

Every minute droplet in the cloud is condensed, and, as a rule, on a grain of dust. This connection between clouds and dust is so important that, though we have already mentioned it, it will be well to note it again here. Dust and ions are the scaffolding of clouds, and without these they could not be built. Were there no dust or ions in mid-air, the water-vapor could condense only where it touched solid bodies on the actual surface of the earth, and all the rain that comes from the clouds would have to weep itself out on the mountain tops Down the high hills torrents of rain would pour, and probably high buildings would also condense continual rivers of rain.

THE EVENING BEAUTY OF CLOUDLAND

THE FLEECY CIRRUS CLOUDS THAT FLOAT IN THE THIN UPPER AIR



THE PILED SNOWY CUMULUS CLOUDS THAT ENCUMBER THE HORIZON

Further, the condensation of the water-vapor on the mountain tops would cause a partial vacuum there, and towards all mountain ranges damp winds would go. Indeed, all damp winds would be drawn to the hills, so that the plains would be deprived even of dew. On the plains, accordingly, all vegetation would die, and they would become desolate, barren plateaus traversed by deep canyons. The presence of dust, therefore, in the atmosphere is one of the many wheels within wheels that serve to render the world habitable. Nor is dust ever wanting

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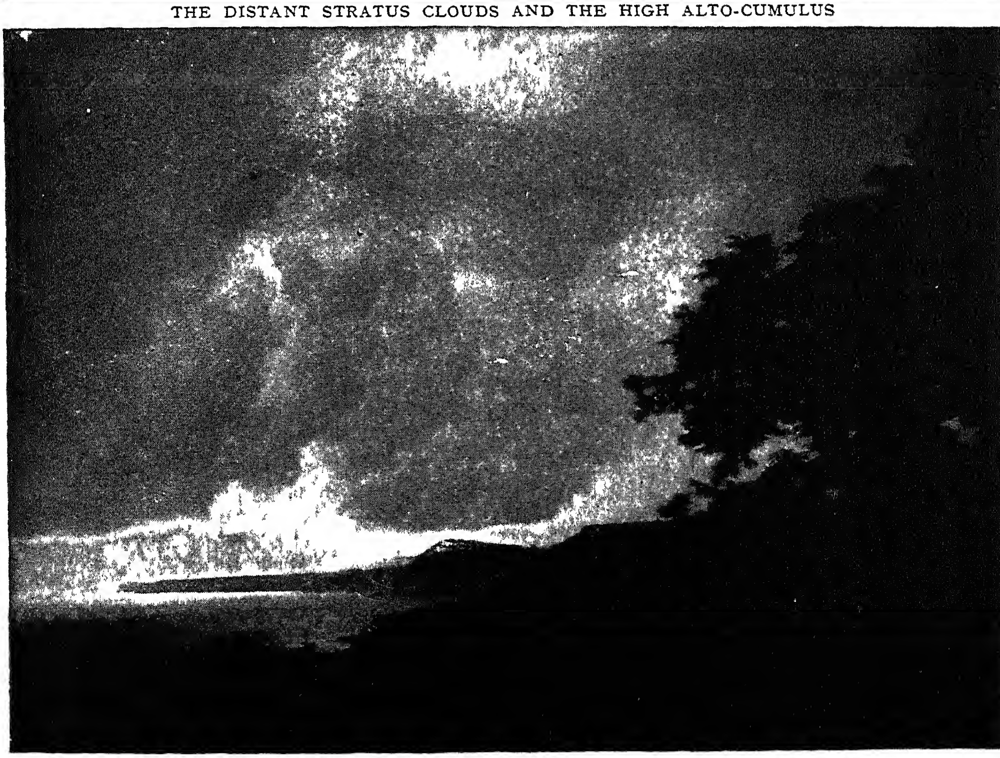
THE SUN'S RAYS "DRAWING WATER"

There are constant supplies of it torn by the winds from the deserts of the world, belched forth by volcanoes, tossed forth by swaying trees, smoked forth by roaring furnaces. Many miles high the dust must be borne, for clouds are formed ten or more miles high. This dust is constantly in the air, carried aloft from the surface of the earth, from volcanoes and desert regions.

Though all clouds rain in a sense, it is not all clouds that condense into drops large enough to produce rain, or that produce enough rain to reach the earth. On the African Karroo, in the dry season, rain-bearing clouds accumulate day after day. Day after day the sky is darkened with them — great, heavy, lowering clouds, which seem almost to touch the tops of the kopjes — but the great cloud-army crosses the sky and spills not a drop of rain. And yet the clouds may have contained enough rain to make the whole Karroo blossom like a rose. No wonder, then, seeing the importance of rain, that layman and scientist have both had dreams of finding some way of emptying the great cloud watering-cans upon the thirsty land. The man who succeeds in finding a way to empty a cloud where rain is wanted and prevent its discharge where rain is not wanted will be a benefactor to mankind.

On the supposition that thunder brings rain, it has often been imagined that rain might be induced by explosions and loud noises, and it was commonly held that the thunder of artillery caused the clouds to pour out rain. But experiment has rather exploded this idea. Indeed, it is based on an unsound theory, for it is not the thunder that produces the rain so much as the

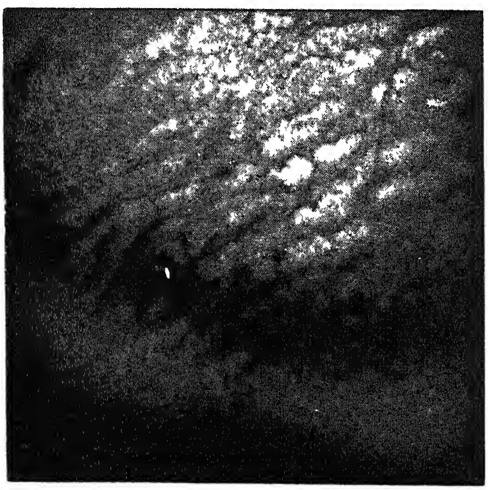
THE DISTANT STRATUS CLOUDS AND THE HIGH ALTO-CUMULUS



THUNDER-CLOUD—A BLEND OF CUMULUS AND NIMBUS

rain which produces the thunder The thunder is due to the increase of electric tension and the leaping through the air of complementary electricities, and the electric tension is increased by the conglomeration of the minute cloud droplets into raindrops; and any direct effect of thunder and lightning in causing a fall of rain is due not to the noise of the thunder, but to the effect of the electrical discharge of the lightning in producing ions which act as centers of condensation.

The fact that they can so act has led to attempts to condense clouds and mists by electrical charges. So far, attempts, restricted chiefly to London fogs, have met with small success



CIRRO-CUMULUS, OR MACKEREL SKY

But clouds are more than aggregations of fine dust and fine drops of water: they perform other functions besides watering the earth, for they serve as regulators of heat. On the one hand, they act as wet packs and wet compresses, keeping in the heat of the earth; on the other, they act as parasols and tents to keep off the heat of the sun. Their action in the latter respect is well known. We all know the sudden chill that falls upon the earth when a cloud passes in front of the sun. We all know the difference in the heat of the sun when skies are cloudy and when skies are clear. But the action of the clouds in conserving the heat radiated from the earth is not so well known. And yet it is of great importance.

When the sun heats the earth, the earth, like all hot bodies, radiates away its heat again, and if the atmosphere be clear the heat leaks away rapidly and irretrievably. But if we put the glass of a hothouse between the earth and the sky, the heat radiated from the soil is radiated back again from the glass, and so is economized and conserved. Just like the action of the glass of a hothouse is the action of the clouds. Supposing the early part of the day has been sunny and bright, and the earth and sea well warmed by the sun's rays, then a cloudy sky in the evening will act as a blanket and keep the earth warm all night by radiating back the heat that would otherwise leak away. If there are no clouds, the heat will radiate away fast, and thus it happens that clear, starry nights are often frosty, and that dry climates have more violent changes of temperature than wet ones. On the island of Teneriffe, where the sun shines all the morning, and where a cap of cloud is condensed on the Peak almost every afternoon, the heat acquired by day is conserved by night, and the difference between night and day temperatures is very small Dr. Samuel Haughton estimates that the heat supplied to the west coast of Ireland by condensation of vapor as clouds and rain is half as much as the sun supplies. The heating value of the Gulf Stream is often emphasized; but water is of more heating value as water-vapor in the air than as warm waves in the sea.

The colors and shapes of clouds are very striking. In an eloquent passage Reclus declares: "Among all the images, whether fearful or graceful, that the fancy of man can dream of, there is not one which is not to be found in the vapors of space. By their fugitive outlines clouds resemble flights of birds, eagles with outstretched wings, groups of animals, reclining giants and monsters like those of fable. Other clouds are chains of mountains with snowy summits; others, again, represent immense cities with gilded cupolas. Poets see in these groups distant archipelagoes, where the happiness so much sought for, and which does not exist on this earth, is to be found. Superstitious people, often pur-

A CLOUDBURST IN SOUTHERN UTAH

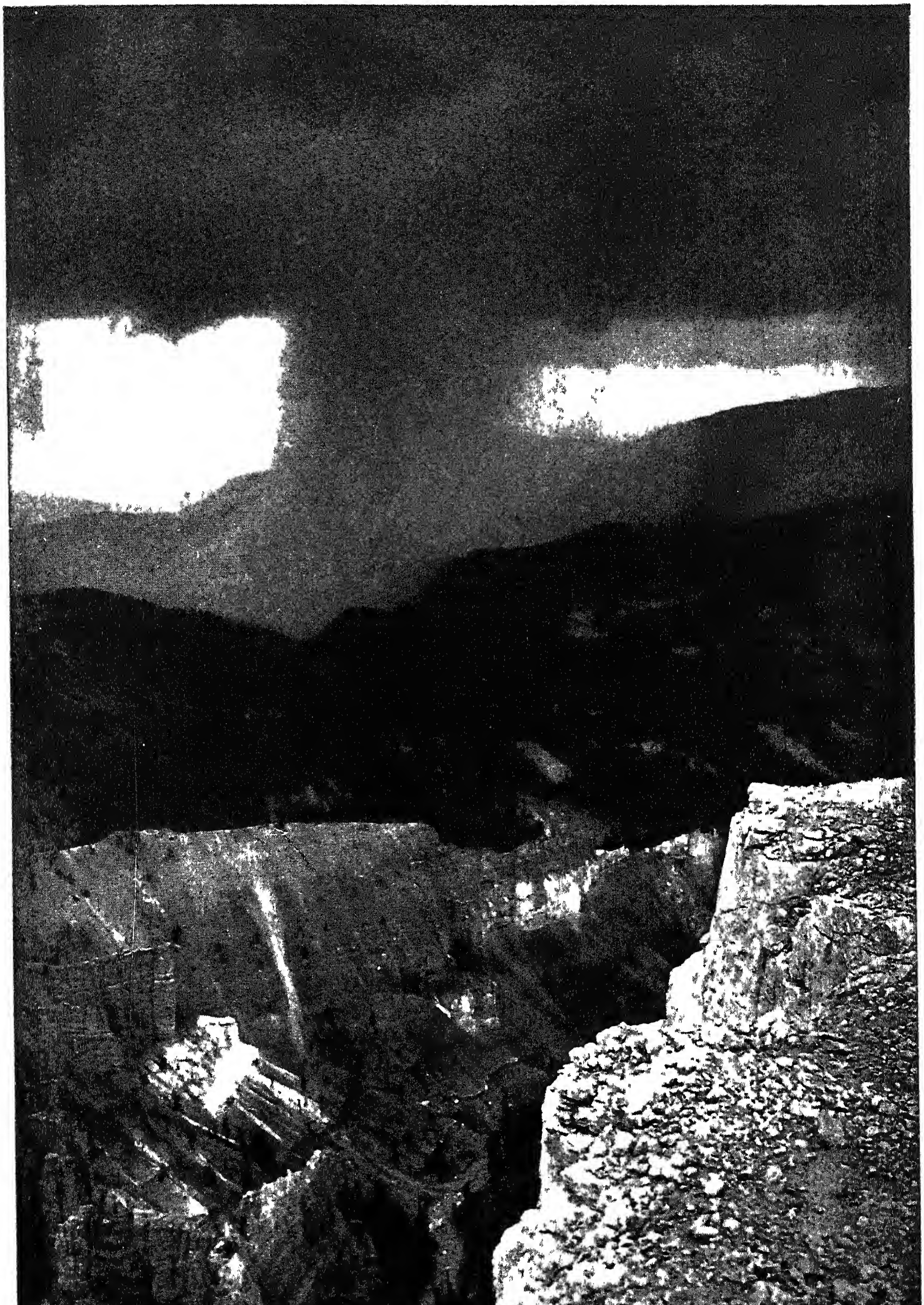
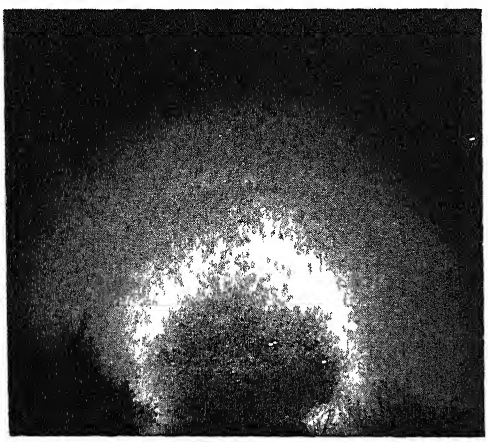


Photo De Cou © Ewing Galloway, N. Y.

A snapshot of a cloudburst in the mountains at Cedar Brakes, in southern Utah, with the great canyon in the foreground.

sued by the terror of their own crimes, see in them bundles of weapons, war-horses, armies in battle array, and massacres. The light playing in this fantastic world of images increases still more their astonishing variety; all imaginable shades shine over these floating bodies, from snowy whiteness to fiery red; the sun colors them successively with all the graduated tints of dawn, daylight and sunset; meadows and forests are reflected there in greenish tones, and the sea itself is produced vaguely by a color of metallic brilliancy recalling that of copper or steel."

The coloring of clouds has become to us rather a commonplace — so much a commonplace that we accept it with more admiration than wonder. "But what," asks Ruskin, "should we have thought if



A SOLAR HALO

we had lived in a country where there were no clouds, but only low mist or fog — of any stranger who had told us that, in his country, these mists rose into the air and became purple, crimson, scarlet and gold?"

How does it come that clouds are colored? They are colored mainly by the dust. The molecules of air, also, are of the proper size to break up the rays of light to cause color. The color, like the blue of the sky, is due to the scattering of certain waves of light as they break on the dust particles. So infinitesimal are the waves that dust is to them as rocks are to the billows of the sea. It is chiefly at sunset that the most gorgeous colors appear, because then the rays of light slant through the lower atmosphere, which is charged with the larger particles of dust; and so the longer waves, the red and orange, are broken, and stain the clouds.

Though the shapes of clouds are so various, meteorologists have attempted to classify them The original classification, made by Luke Howard in 1803, considering form only, distinguished the following shapes: cirrus, cirro-cumulus, cirro-stratus, cumulus, cumulo-stratus, stratus and nimbus More recently, however, the International Meteorological Committee have divided clouds into ten classes: cirrus, cirro-stratus, cirro-cumulus, alto-stratus, alto-cumulus (great waves), strato-cumulus, nimbus (rain-clouds), cumulus (wool-pack clouds), cumulo-nimbus (thunder-cloud or shower-cloud), stratus.

The three chief types are the cirrus, stratus and cumulus.

Cirrus clouds, as the name (*cirrus*, a curl) indicates, are curly, white clouds. By sailors they are known as "cats' tails" and "mares' tails". There may be thousands or tens of thousands of these curly wisps in the field of sight at one time, and they are often arranged in belts of parallel rows.

Cirrus clouds always float five or ten miles high, so high that they often drift in quite contrary directions to the lower cloud, so high that their vapor is frozen into minute crystals of ice. The faint haloes which sometimes appear round the sun and the moon are due to these crystals. When the crystals melt, the cirrus floats lower and becomes a cirro-cumulus, small globular masses arranged in groups or lines producing the appearance of mackerel scales. The cirrus may become a cirro-stratus, and spread as a thin film or tangled web over the sky. This form of cloud also consists of crystals, and forms haloes round the sun and moon. The cirrus usually presages wind, with rain or snow.

The cumulus, or wool-pack clouds, the "cloud-chariots" of Ruskin, are the most majestic and impressive of all. They look like colossal fleeces piled up into a dome on a horizontal base, and often,

on the horizon, look like a range of snowy mountains with rounded summits. The cumulus moves in a solemn and stately manner, and, since it represents a very heavy load of moisture, it does not float at the same altitude as the cirrus, and rarely is more than a mile above the surface of the earth. When cumulus clouds are closely packed into rolls and cover the whole sky they become strato-cumulus. The cumulus cloud is formed by the condensation of currents ascending from the heated, warm, moist air, and it is therefore a day cloud, and especially an afternoon cloud. When of moderate size, and melting away towards evening, they usually indicate a spell of good weather; but if they are of huge size, and do not melt away in the evening, they signify rain.

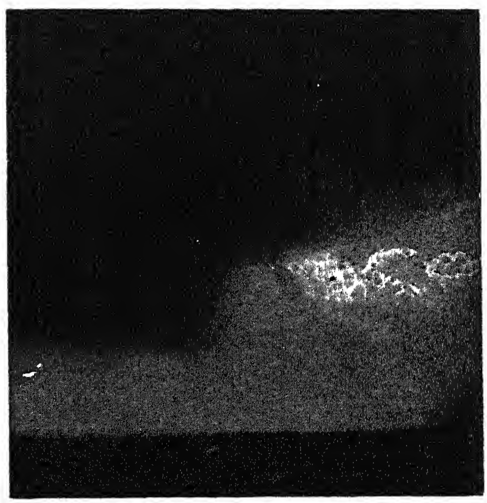
The stratus cloud is a uniform layer, or sheet, of cloud floating less than half a mile above the ground. It is almost exclusively a night cloud, usually formed towards evening, when the cooling of the earth's surface condenses vapors that in the heat of the day have been floating at greater heights. When it occurs in the morning it is often dissipated during the day, and it is indicative of a continuance of good weather. When it is broken up into irregular shreds it is known as "fracto-stratus".

The nimbus is a dark, thick, shapeless cloud with ragged edges, from which rain or snow usually falls. It floats about a mile high, and from its top surface it throws off cirri, known to sailors as "scud", and more or less numerous in proportion to the severity of the rain-storm. A modification of the nimbus is the cumulo-nimbus, thunder-cloud, or shower-cloud. Its base is a dark, thick, shapeless cloud like the nimbus, but it is topped by heavy masses of cloud rising in the form of mountains, turrets or anvils, generally surmounted by a sheet or screen of fibrous appearance (false cirrus). Sometimes, especially in the case of spring showers, cirrus clouds are also given off from the edges of the cumulo-nimbus.

The proportion of sky covered with cloud is generally registered by meteorologists according to a scale in which 0 represents a cloudless sky, 5 a sky half clear and half clouded and 10 a sky which is covered with cloud or overcast

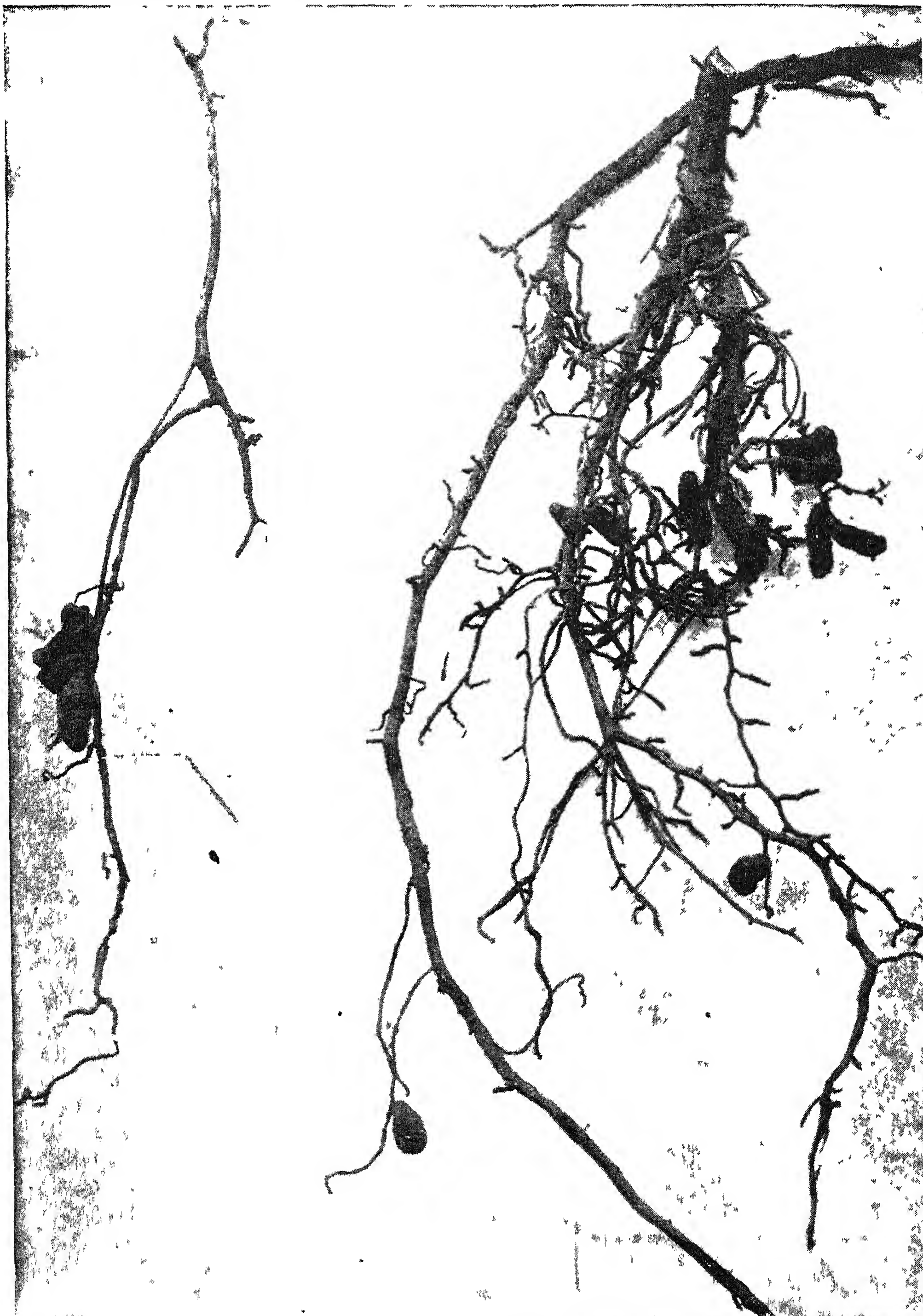
Under the category of clouds we may consider dew A dewdrop is just a lowly cloud-drop, though for centuries the source and nature of dew was involved in much obscurity. It was noticed to be most plentiful on clear, calm, starry nights; hence the ancients conceived the beautiful idea that the dew came from the stars, and when it was noticed that there was most dew on cold nights, the cold, too, was supposed to come from the stars.

But closer observation upset this theory, for it was found that dew sometimes forms on the under surface of leaves and



A RAIN SQUALL — NIMBUS CLOUD WITH CUMULUS IN THE DISTANCE

stones, and that its formation depends very much on the nature of the object bedewed. And so it became understood that dew is simply moisture condensed on cold bodies, much as the human breath condenses on a cold mirror. The reason why clear, calm, cloudless, starry nights are dewy nights is simply that on such nights the heat from the surface of the earth radiates away more freely, and the cooled objects therefore become more efficient condensers. On cloudy nights the clouds act as a blanket, and keep the surface of the earth warm, and the warmer surface fails to condense moisture and to form dew.



In this photograph of the roots of the laburnum-tree are seen the attached nodules formed by the nitrifying bacteria which appropriate and fix the nitrogen of the air in the soil and use it to build up the nitrates which are absorbed by the roots for the nourishment of the tree.

From a photograph by Mr. J. J. Ward

THE GREAT CYCLE OF LIFE

How Energy from the Sun Rendered Available by the Action of Green Plants Serves both Plants and Animals

THE PRIMAL MASTERY IN THE GREEN LEAF

If we are to understand the great issues involved in the coming conquest of disease, we must look at them not medically, still less medicinally, but biologically. So says modern science And therefore we have to begin by looking at the age-long revolutions of what is often called the cycle of life. We must trace its parts in their order of succession and causation, if we are to see where what we call disease comes in, and if we are effectively to put a spoke in its wheel. The evolutionary or historical problem does not concern us here; it is enough for us to take the sequence of events as we can trace it now. If we follow what is, so to speak, one complete revolution of the cycle, we shall see the world of life as a balanced whole, of which the parts are interdependent; and we shall also see the place where the great problems of disease arise.

We begin with sunlight, a form of energy which pours down upon the earth. No doubt life has a certain capital stored up in the earth, in such forms as coal or "buried sunshine". But the consumption of that capital is only a passing chapter in the history of life, and it was indeed accumulated in the very fashion which we are about to describe. The actual sunlight of the present is the income upon which Life lives; and if we trace the expenditure of life's income, thus defined, we have all the main facts before us.

The existing life upon which the sunlight falls must somehow avail itself thereof. The first demand of all living things is food, and their food invariably includes carbon in some combustible form. Now, the air contains a quantity of carbon, in the form of carbon dioxide, CO_2, a gas which occurs in the atmosphere to the extent of some four to six parts in ten thousand. But no animal, high or low, ancient or recent, can avail itself of this carbon; nor, if the carbon be given to it ready made, can the animal utilize it If you eat a charcoal biscuit, or swallow a few diamonds, or enjoy coal out of the scuttle, as children occasionally do, you embody the carbon, but you do not employ it. Carbon in this form is of no use for the immediate purposes of life If it is to start the cycle of life, it requires to be in the form of carbon dioxide, CO_2, completely burnt carbon, which, as we have seen, no animal organism can employ, but which every animal organism produces, and must be rid of or die.

The green plant alone has the mastery here. If we load it with carbon in the form of soot, as in any of our cities, it profits not at all, though carbon it wants and must have. Though it wants the carbon in order to burn or oxidize, the curious fact is that it cannot utilize unburnt carbon, but requires to go for it to the already burnt carbon we call carbon dioxide. Now, this substance is a very stable compound of carbon and oxygen. The respective atoms are united very firmly. The measure of this firmness is the amount of energy, in the form of light and heat, which is given out when carbon burns and carbon dioxide is produced. It follows that, if the chemist seeks to undo this combination, he requires to use a great quantity of energy for the purpose. In fact, he commonly finds that he can effect this dissociation, as it is called, of carbon dioxide only at a temperature of thousands of degrees.

But the green plant does it in the ordinary air of day, without sound or fuss, and it is in this dissociation of the carbon dioxide of the air that the cycle of life starts rolling. The essential medium of the process is the green matter, called chlorophyll, which is characteristic of nearly the whole of the vegetable world. In some cases it is replaced by a similar substance, yellower or browner, or even coppery in hue, but all are essentially the same, and have the same function. Chlorophyll is a transformer. It is not in itself a source of energy; on the contrary, chemical energy was spent by the plant in making its chlorophyll in the first place. But it has, in utterly unique degree, the power of transforming or directing certain parts of the energy of sunlight. The parts of the spectrum concerned are especially those which lie near, and also beyond, the violet end. Thus in these "actinic", "chemical", "photographic" rays — which might be called *biogenic*, or life-begetting — and in their source, the sun, do we find an essential condition of earthly life as we know it.

How light aided by chlorophyll breaks up carbon dioxide

What is the rôle of the chlorophyll in this dissociation of carbon dioxide under the influence of sunlight? The energy which the plant, like the chemist, requires is that of the sunlight The chlorophyll must be looked upon as a means or instrument which enables the living cells of the plant to utilize the energy of the light, so as to produce the chemical result. Within recent years chemists have been able to imitate this process "in a very feeble way", as Sir James Dewar himself says, who twenty years ago succeeded in decomposing the weak compound iodoform — very different from the stable compound which the green leaf decomposes — by simply passing electric light through it. But though a poor parallel, it is a true one, a compound being dislocated by the actinic rays in electric light just as the carbon dioxide is dissociated by the energy of the actinic rays of sunlight, when utilized and directed by the chlorophyll-bearing cells of the plant.

The history of an atom of liberated carbon

So much for the first stage of the cycle of life, in which man is merely an incident, as we shall see. Now let us trace further the history of the carbon thus obtained by the plant. If it simply remained as uncombined carbon it would be of no use to the vital processes of the plant, nor would it be of any use to us. We must observe that, simultaneously with this dissociation of the atmospheric carbon dioxide, the plant is helping itself to water, H_2O — not from the air, however.

It has begun to rain, let us imagine, and the leaves we look at are all dripping wet, yet not one is absorbing a single molecule of water. It is the function — one function — of the leaf, as of our skins, to give off water, not to take it in; and the process is known as transpiration. Hence the French word for "perspiration". The plant perspires or sweats by its leaves, thereby keeping itself cool, as we do, but it drinks only by its roots, just as we drink only by our mouths, and absorb no water from a bath. In both cases, the essential water cannot be taken in haphazard, anywhere, and anyhow, for it has a definite course to run, through the body of the living thing; and so its place of entry is limited, and its future doings are well defined.

The absorption of water to combine with liberated carbon

In us, and in all animals, the water remains as water, and leaves the body as water, though in large degree with certain substances dissolved in it. But the green plant is very different in its chemistry, and can do what no animal organism can do, and without which no animal organism could exist. The water absorbed by the roots of the plant passes up the stem, against the pull of gravitation, by the plant's own special devices, until it reaches the leaf, where there awaits it, as it were, the carbon which has just been wrested from the air. The leaf is the living laboratory of the plant, and therefore of the animal.

Somehow there the living protoplasm — possibly by means of a ferment or ferments elaborated for the purpose — combines the carbon and the water so as to form certain substances called "carbohydrates."

Theory of what goes on in the plant cell in forming a carbohydrate

These substances, of high importance in chemistry and biology and dietetics, consist of carbon, C, combined with hydrogen and oxygen in the proportions in which these two elements unite to form water, H_2O. All the starches and sugars are carbohydrates, that is, compounds composed of the elements, carbon, hydrogen and oxygen. If we take a typical sugar, such as glucose, we find its "formula" to be $C_6H_{12}O_6$, the figures indicating the number of atoms of carbon, hydrogen and oxygen respectively that are combined to form a single molecule or unit of this sugar. Just what the actual changes are that occur in the transformation of carbon dioxide, CO_2, and water, H_2O, into sugar is still a matter of conjecture. It is known that in this process oxygen is set free and is given off by the plant as a waste product. This knowledge, supported by what we know of chemical reactions, enables us to suggest the following explanation. CO_2 and H_2O enter into solution within the cell to form carbonic acid, H_2CO_3, which is then decomposed to formic acid, CH_2O_2, thus setting free one atom of oxygen. A similar decomposition of the formic acid then follows, which brings about the formation of formaldehyde, CH_2O, with the liberation of a second atom of oxygen. In the presence of certain acids and alkalies formaldehyde increases the number of elements that compose it, so that six times CH_2O would give $C_6H_{12}O_6$, which is the formula for grape sugar. While this suggested explanation of what goes on within the plant cell in the process of formation of a carbohydrate is consistent with our knowledge of chemical reactions, it is, nevertheless, only a theory. All that we actually know is that CO_2 and H_2O enter the green cells of the plant and that in the end a carbohydrate appears in the cell and oxygen is liberated as a waste product.

The green leaf has now done its essential work. It has gathered in so much of life's income as fell upon it, and has converted that quantum of energy into the "chemical energy" of starch and sugar. You see the process going on in the green leaves of potatoes or wheat. In due course, the solar energy thus captured and transmuted will be appropriated by the animal world — as, for instance, by any consumer of potatoes or bread — and the cycle of life proceeds on its course.

Chemical energy of starch and sugar consumed from the leaf to support all life

Every animal body in the world is thus supported. The animal may live directly upon the green plant, as vegetarians do, or may live upon an animal, such as the sheep or the ox, which has lived upon the plant. In any case, we consume the bodies and avail ourselves of the products of green plants — the vegetarian must perforce be, as Stevenson calls him, the "eater of the dumb". The whole of the animal world, from the humblest microscopic amœba or malaria parasite, up to and including man, is thus supported upon and by the green leaf. Without it, we should not be.

However, one must not say we *could* not be. For it is to be observed that there is nothing in this description, so far as we have gone, to negative the possibility that man may at any time reduce the number of stages and intermediaries in the processes by which he is fed, or by which any animals he cares for may be fed. At the present time, as throughout the past, the green leaf is essential, but we have insisted that it does not create. It only transforms. The energy whereby the whole animal world, like the whole vegetable world, lives is solar. There is no reason why, with more knowledge, man should not directly bring solar energy so to bear upon carbon dioxide as to dissociate it, and even thereafter cause the carbon thus obtained to unite with water and thence lead up to the carbohydrates.

But those who have looked closest into these processes are best aware of their difficulty. It is not as if soot or diamonds could be dropped into water, and formalin

be the result, nor does chemistry find it exactly easy to construct starch or sugar out of formalin. Further, we are to observe that the animal world requires not merely the carbohydrates of the plant, but also its proteins, which the plant is able to make for itself, and which no animal can make. Thus, though there is no theoretical reason why man, having the solar energy at his disposal, should not be able to "short circuit", so to speak, and run the solar energy directly into the making of compounds for his nourishment, yet for ages to come, in all probability, if not always, he will find that the laboratory of the leaf is better, more convenient, cheaper, more efficient, than any he can devise.

The passage of carbon back to the air from plant and animal

However that may be, we have now traced the carbon that was part of the atmosphere, now much transformed and combined, into the mouth of an animal, whence it passes to glands and muscles and brain and bone. Soon the greater part of it is there oxidized or burnt, thus yielding carbon dioxide in the tissues, whence, by means of the blood and the lungs, in the case of the higher animals, it returns to the air. In all animals whatsoever this is the necessary sequence of events — the carbon dissociated by the plant is again associated, and carbon dioxide is restored, in its former form, to the air whence it came. Every expiration which punctuates the writing or the reading of these words is thus essentially the completion of what is called the carbon cycle — that part of the cycle of life which consists in the passage of carbon, derived from air, through the bodies of plant and animal in succession, and back to the air again.

The lengthening or shortening of the "carbon cycle" from air back to air

Of course, the process may be delayed or shortened, and its number of stages may be various. The plant is not necessarily eaten by an animal; the plant itself breathes, and partly restores to the air the carbon it takes from the air. The animal which consumes the plant may be consumed by a second animal, and that by a third, such as man, who may in his turn be eaten by a cannibal, or a lion or a shark, but these details do not affect the essential sequence of events at all. In the long run, the carbon cycle is completed as we have described. Even the case of gasoline, peat, coal and other accumulations of carbon made by former vegetable life is only a kind of variant of the rule — animal life consumes vegetable products even so, and the atmosphere gets back its carbon dioxide even after millions of years.

Looking broadly at these facts, we must remind ourselves that the plant, or, rather, the green plant, is very definitely contrasted with the animal, in that the plant largely builds up what the animal largely destroys. The plant stays where it is, spends little, is thrifty, steadily accumulates, stores up, in the form of starch and sugar, the energy which falls upon it, so that instead of carbon dioxide, which is in itself, so to speak, finished, completely burnt and used, the plant provides us with compounds which can yield much energy.

The spending by active animals of energy collected by stationary plants

The animal spends this energy, gadding about, doing things, and breaks down the steady upbuilding of the plant into the simple constituents with which the plant began. In the terms introduced by Sir Michael Foster, the great process of metabolism, or chemico-physical change, which is associated with all life, has an upward stage, anabolism, and a downward stage, katabolism; and it is the plant that is constructive, accumulative, anabolic, and the animal that is destructive, spendthrift, katabolic. Without what the plant saves, no animal could spend and as the animal lives by spending, no animal could live.

In the foregoing we have specially described what we called the carbon cycle. But we might equally well have devoted ourselves to what may be called the nitrogen cycle. All protoplasm contains, and must contain, proteins. all of which contain nitrogen.

No animal can use this element nitrogen in its elementary state. The blood of every one of us contains quite a quantity of elementary nitrogen, absorbed from the air, of which it constitutes something like four-fifths; but we profit by it not at all. No doubt bio-chemical research has lately shown that the animal organism is capable of much more anabolism than used to be thought possible for it, but it can no more build up proteins than it can build up carbohydrates, though proteins, even more than carbohydrates, it must imperatively have, or die.

The absorption of nitrogen through the roots of plants for a nitrogen cycle

Again, it lives upon the plant. What the animal needs the plant needs also. It must have proteins for its protoplasm, or die, and though it is exposed to the same nitrogenous atmosphere as the animal, it is similarly impotent to absorb nitrogen as such and utilize it. The sunlight and chlorophyll, which enable the plant to feed on the carbon in the carbon dioxide of the air, do not avail it for the nitrogen. We must turn from the plant's leaves to its roots, where we saw it absorbing water. In the soil there are compounds of nitrogen which the plant can use. We call them inorganic compounds of nitrogen — such things as ammonia and its salts, and nitrates of various metals — and we can prove that the plant absorbs them. No animal can utilize these compounds and build them up into proteins, any more than it can use the free nitrogen of the air. But the anabolic, constructive plant can take these simple salts, and can build them up into proteins.

The resting of the animal on the plant world, through the nitrogen cycle

As to how this is done, or the stages in the doing of it, we must confess ourselves wholly ignorant. In the case of carbon we were able to form a very fair mental picture of the meeting of carbon and water, the construction of a sort of very simple carbohydrate and its elaboration. But to trace an ammonium salt or a nitrate upwards to a protein is entirely beyond our present powers. The complexity of the problem may be realized when we learn that carbohydrates are themselves but details in the composition of a protein · as we know from the fact that when proteins break down carbohydrates appear, as in the production of sugar from the proteins of the body in the disease called diabetes. We cannot yet expect, therefore, to trace the nitrogen in its anabolic course, from a mere nitrate up to the most complicated compounds known to chemistry, which the proteins are. But the fact of this ascent remains, and the further fact that no animal organism can contrive it, though no animal organism can do without its product.

Again we find the animal world resting upon the vegetable world. But recent inquiry has shown that the nitrogen cycle is really very much more complicated than the carbon cycle. For we now know that many green plants are aided in their anabolic work by the services of certain *not* green plants, "bacteria", as they are called, which live in the soil, often attached to the roots of the green plant, and have the power of fixing the nitrogen in the soil air, and turning it into salts, which the roots can then absorb.

The help given by the bacteria of putrefaction in releasing animal constituents

That is a very remarkable story, for it gives to certain bacteria a high place in the sequence or cycle of life. They help to make the bread by which we live. As Mr. Hall and Dr. Russell have shown, further complications arise, for minute animal organisms live in the soil, and are liable to consume some of these useful bacteria. That is no concern of ours here, except in so far as it serves to illustrate further for us the complexity and the interdependence of processes and persons concerned in the balance of nature and the cycle of life. Even Darwin's most fascinating illustrations become simple and unimportant compared with what the microscope has since revealed.

But the cycle is still far from complete, even though we observe the excretions of the animal, such as carbon dioxide, and

observe their identity with our starting-point. The individual animal dies. It may have a living tomb in the body of some carnivore. It may be burnt, and thus at once reduced to simple substances, such as carbon dioxide and water. But the normal typical destiny of the animal body, sooner or later, is to sink into the soil. If it so remained, the continuance of life would soon be impossible, the cycle of life would have to stop rolling. But that is not so, for the soil, we remember, is the environment of the roots of the green plant, and provides it with food. Once already we have seen bacteria play a useful part; and now we learn of more essential uses still. The "nitrifying bacteria", as they are called, which fix the atmospheric nitrogen, are but a subsidiary group, valuable though they be. Essential, however, for the continuance of life are the ordinary bacteria of putrefaction which abound everywhere, but preëminently in the presence of animal or vegetable matter from which the life has departed.

The special poison of plants that have no chlorophyll

Again and again we have spoken of the plant and the part it plays in the maintenance of the animal world. But we always meant that great anabolic, constructive agent, the green plant. Now we encounter, with a full sense of its importance, a subdivision of the plant world, of which the very existence was unknown until the nineteenth century.

All plants whatsoever which are destitute of chlorophyll are called fungi. Their deficiency compels them to live, not as all green plants do, but as all animals do, by destruction or katabolism, instead of construction or anabolism. We call them plants because we cannot call them animals, and for some other reasons, but they are practically, and as regards their place in the cycle of life, a kingdom apart.

The lack of chlorophyll, with the dietetic necessity which that imposes — for the plant cannot feed on air, cannot live by energy of sunlight, and must therefore get that energy indirectly from plants which can, as animals must — puts the mushroom or the toadstool and the invisible fungi in one and the same class. The invisible ones are immeasurably the more important. When the microscope makes them visible, we see that they divide and multiply by splitting, and we therefore call them the fission-fungi, or schizomycetes. They are commonly longer than they are broad, and we call them bacteria, and the study of them bacteriology. They may be quite rod-shaped, and we call them bacilli; or round, and we call them cocci, but bacteria is to be understood as the general name. All bacilli are bacteria, but only bacteria of a certain shape are bacilli.

Really, the shape is nothing, but the habits are everything. In brief, we may say that, normally, originally, properly, bacteria live upon *dead* organic matter. It must be organic matter, made by pre-existing life, because the bacterium, being without chlorophyll, cannot use sunlight in order to build up organic compounds for itself from inorganic materials. The technical name for a bacterium (or for any fungus, of course) that lives upon dead organic matter is saprophyte, and such an organism is said to be saprophytic. The name is not pretty, and the mode of life is not beautiful, nor do our noses commonly appreciate some subsidiary results of the process. But without it neither we nor our noses should be here.

The scavengers of the world that break down the bodies of the dead

Let us leave aside the special uses of the saprophytic bacteria — their services in the curing of tobacco, the tanning of leather, the making of synthetic rubber and a thousand other processes which depend upon their powers as ferments. Those uses daily increase in number and importance; and people are gradually coming to realize that there are useful bacteria, which can be put in harness for human purposes. But all these uses are entirely trivial compared with the universal and essential business which the bacteria as a whole perform — the breaking down of the bodies of the dead. Without this agency and these agents, the cycle of life could not be maintained in motion. Frequently we hear it

stated that the bacteria of putrefaction are the scavengers of the world, clearing away offensive matter. But in fact they make it "offensive", as we call it. Without them it would be quite innocuous to our senses, and would simply remain as it is. The bodies of the dead would not decompose or rot. They would simply accumulate.

Bringing back to the earth nitrates for future use

The function discharged by the bacteria is to make the bodies of the dead available for the purposes of the living. They set to work, with their sharp, invisible teeth, which we call ferments, to tear to pieces and disintegrate those elaborate compounds, from the proteins downwards, which they find in the bodies of animals and plants alike, and the history of which we have traced. This is not the choice of the bacteria, but their necessity. Their lack of chlorophyll compels them to be saprophytic. Possibly they are to be classed as degenerate, and as having fallen from the higher state of such simple green plants as the algæ. No doubt their processes are simple, and their personal development very limited, but they make us possible.

The animal body, high or low, no matter whom or what it housed, dies and returns to the dust. The microbes of putrefaction resolve it into sulphates, phosphates, nitrates and so forth, of various metals — calcium, sodium, potassium, in especial. Now, we said a little while ago that "in the soil there are compounds of nitrogen which the plant can use". A fair question, then, would have been — Whence do they come? Here we have the answer. They come from the bodies of the dead. The cycle of life is complete. No doubt every species lives for itself, seeking to realize and amplify and intensify life along its own lines. No doubt, as Darwin said, there is no case of any species having any characteristic evolved for the purposes of another. But they are all one, nevertheless. As we dwell in this our "isle of terror", each of us is inalienably bound to all the rest. So you may be selfish for a century, but at last others will claim your dust. The whole creation groaneth and travaileth together.

Man's interference sometimes seriously upsets the balance of nature

At every point Life tries to assert itself; it does so in the living, and then avails itself of them, in another way, the moment they are dead. And though the struggle for existence seems internecine, it is really the shortest way to the most life; and the lowest of the forms which compete in it may be found indispensable for the existence of the highest forms.

Two large and important conclusions emerge from this study:

The first has very often been pointed out, and still more often illustrated. It is that human interference with living forms must necessarily have far larger consequences than will at first sight appear. We see some kind of creature living somewhere — somehow, as to which we do not think — and we exterminate it. We want to eat it, or it is dangerous, or it is excitingly interesting to hunt.

On the other hand, we come to like a species, and we introduce it into a new habitat. But only critical inquiry, in each individual case, and not always even that suffices, can set a limit to the consequences in terms of the survival or disappearance of *other* species, which may be indefinitely remote in the scale of nature.

Flies breed in and feed upon the refuse of horses. The bacteria engaged in breaking down the refuse are carried by the flies into houses, reach babies' mouths, and kill them, like flies, every summer. The invention of the internal combustion engine and the slow disappearance of the horse from cities thus directly leads to the increase of surviving babies. This is a mere instance, quoted because it happens to be fairly recent. It is also a favorable one, but that is a mere accident.

In very many, innumerable, other cases, man disturbs the balance of nature having no conception of such a thing, and the results are disastrous. We should undoubtedly walk more warily and wisely in these matters if we had any adequate conception of what is called in this chapter "the cycle of life".

Microbes good and bad — indispensable and injurious

Secondly, we learn once and for all that we cannot do without bacteria or microbes, as Pasteur called them. Essentially, primarily, originally, they are to be looked upon as beneficent. Yet we all know not only that some of them cause disease, but that they cause nearly all disease. Clearly we require some sharp distinctions here. A special name is easily made for disease-producing microbes; we call them pathogenic. And what constitutes their "pathogenicity"?

The typical microbe, we said, is a saprophyte. It feeds upon organic matter which is dead — was alive, but is not. Such a microbe can do no harm — does indispensable good. But other microbes, which are, in all probability, historically, evolutionally derived from the saprophytes, feed upon the tissues of the living. These we call parasites, and the two contrasted terms must be most definitely understood, and used with accuracy. It is possible that there are some saprophytes which can become parasitic on occasion, and some parasites which can become saprophytic, as when the bacteriologist cultivates pathogenic microbes in beef-jelly or milk. Such forms require to have a very close eye kept upon them, plainly; and what we already know of them, so far from minimizing the distinction between a saprophyte and a parasite, only emphasize its importance.

The advent of disease to the great cycle of life

We have much to learn about the possibility of this transition, above all in the dangerous direction. Thus, our bodies harbor microbes which commonly do us no harm that can be defined. Probably they live as saprophytes, strictly speaking, though we are alive, because they merely consume lifeless materials in our food. It is known, however, that at times these organisms, although they do not themselves produce pathogenic results, do produce conditions or an environment that enables pathogenic forms to do their work.

We see, then, where in the cycle of life the possibility of disease arises. It is at that point where the saprophytes are needed to keep the cycle going. They may exceed their functions of breaking down and decomposing dead organic substances and by their activity prepare the way for other forms to attack the living, and that is disease. In due course we shall see that not only fungi, by any means, are parasitic. Far from it, indeed. But the fungi are by far the most important of all parasites, and their place and origin in the natural order has now been defined.

Only one other point needs insistence. It is that there is no more vice or malice or mortal intent in the activity of a parasitic than of a saprophytic microbe. It is merely trying to live as much as possible. Only it may so happen that the requirements and products of its life are antagonistic to the requirements and products of its host.

This is not even necessarily so. On the contrary, many parasites are not pathogenic. They manage to live at the expense of their host, but without injuring him, so far as we can see, for in some way or other he protects himself. And, further, the "success" of the pathogenic parasite is disastrous to it, for where its host is killed by it, its own fate is sealed. Thus we must beware of applying moral judgments to these problems. In fact, they all illustrate Life in various forms doing the best for itself. Only, the process at every turn provides warrant and precedent for what the species we belong to must do for itself, as all the others do for themselves. We must kill these parasites in the interests of our lives; and though our bodies do so with much success, the time has come when we must bring our minds to their aid, and so achieve the prophecy of the pioneer whom we shall shortly study: "Make all parasitic diseases disappear from the world."

Success in the discovery of harmful parasites, and the means of counteracting them, make it by no means an impracticable vision that some of the worst diseases which have scourged mankind may be finally extirpated.

NEW KNOWLEDGE OF DISTANT SUNS AND SISTER WORLDS

WHAT WE KNOW AND HOPE TO LEARN

WITH Schiaparelli's observations of Mercury, Venus and Mars during the last quarter of the nineteenth century there was opened a new epoch in the study of the eight other worlds besides our own which, in all the universe, are known to man. The laws governing the movements of the earth and her eight sister worlds, as well as planetoids, comets, meteors and the satellites or children of the planets, were revealed by Newton. His successors so completely derived the consequences of these laws that it was possible to predict, centuries in advance, the place of any member of the solar system with an accuracy corresponding to that attained in the original observations.

When Schiaparelli began his observations of the planets, little more was known about their surface features or their atmospheres than was known to Cassini nearly two centuries earlier.

By locating our telescopes in those places where the messages brought by the incoming radiations are least blurred and distorted by their transit through our own atmosphere, and by enlarging the aperture of our telescopes, so as to bring to increasingly sensitive receiving apparatus greater amounts of the telltale radiations, we have, in the last quarter-century, greatly extended our knowledge of distant suns and sister worlds.

Kirchhoff and Bunsen in 1859 discovered the third law of spectrum analysis, the first key for deciphering the hieroglyphics in which the incoming radiations from stars and planets tell us about the place from which they came. Our eye, with various aids to enlarge the image of small or distant objects, partially interprets the messages which the visible radiations bring, and the photographic plate has extended the range of the radiations which we can interpret in these ways. The spectroscope analyzes these radiations, and the radiometer adds up all of them and tells us the total amount. Percival Lowell, with his superb telescope, looking through the clear, thin air over the forest-clad plateau of north central Arizona, derived from the observed seasonal changes in the vegetation on Mars, the mean temperature of the planet. Coblentz and Lampland at the Lowell Observatory, and Nicholson and Pettit at the Mount Wilson Observatory, measured with their radiometers the heat radiated by the warm planet Mars, and thus, by wholly independent means, substantially confirmed the temperature of the planet as derived by Lowell. St. John at Mount Wilson, with the most powerful spectrograph yet employed in analyzing the light coming to us from Venus, confirmed Lowell and Slipher's spectroscopic results, showing the long rotation period of the planet. He also obtained spectroscopic evidence of the practical absence of water and oxygen from the atmosphere of Venus, thus confirming the strong suspicion to the same effect derived by Lowell from his visual observations. Since the spectroscopic evidence is not capable of detecting so slow an axial rotation as given by Schiaparelli, Lowell and E. C. Slipher's observations of surface markings of Venus, there is still some question as to whether these results will be confirmed by other means than the observation of these very difficult surface markings.

The spectroscope simply shows the period of axial rotation to be as long or longer than twenty days, while the visual observations of Schiaparelli, Lowell and E. C. Slipher show that Venus keeps one face toward the sun and hence rotates on its axis once in 225 days. Radiometric measures of the heat received from the night side of the planet seem to throw some doubt on the validity of these results, though the present writer is of the opinion that the circulation of the atmosphere of Venus will explain the radiometric results without doing violence to the visual observations of such keen observers. While it is not possible to tell the exact period of Venus' rotation because of its thick clouds, this period is believed to be about 30 days.

St. John also confirmed Lowell's observations showing the presence of water and oxygen in the atmosphere of Mars. The spectroscopic results obtained by him not only establish that presence, but give fairly reliable estimates of the amount of both of these important constituents and substantially agree with Lowell's values derived from the rate of melting of the polar snow caps and from the seasonal changes in his vegetation.

MARTIAN DATES

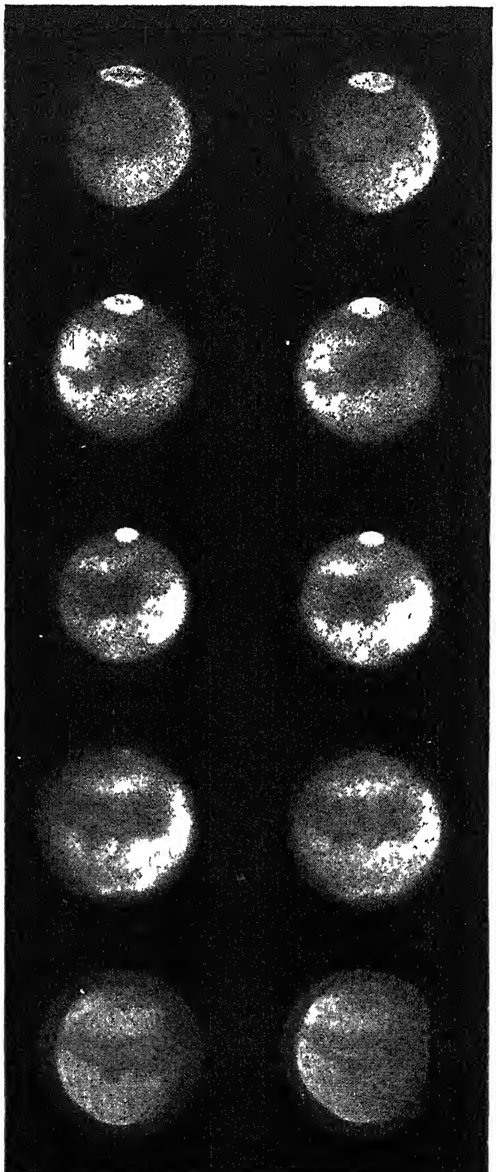
MAY 11

MAY 29

JUNE 23

JULY 31

AUG. 20



Telescopic photographs of Mars, by E. C. Slipher of the Lowell Observatory, showing decrease of the polar snow and the darkening of the planet's tropics during Martian summer. This turning to blue-green of certain regions during his summer and their subsequent fading in winter seem best explained by assuming that their dark areas are due to vegetation.

Photographs of Venus, Mars, Jupiter and Saturn taken at the Lowell and Lick Observatories by means of infra red light, by the visual rays in the green and yellow, by violet and by ultra-violet radiations, are proving to be of great value.

Radiometric determinations which give the amount of heat radiated from Jupiter, Saturn and Uranus show that the region from which we receive radiations from these planets is always colder than any temperature ever experienced on earth, in every case over 100° Centigrade below the freezing point of water. Visual observations, photographs by means of light throughout the visual range and as far on either side as our atmosphere allows, spectroscopic study of the light reflected from these planets, together with radiometric measurements are helping us gradually to unravel the mystery of these cloud-enshrouded worlds.

A TYPICAL GLOBULAR CLUSTER

Courtesy of Mt. Wilson Observatory

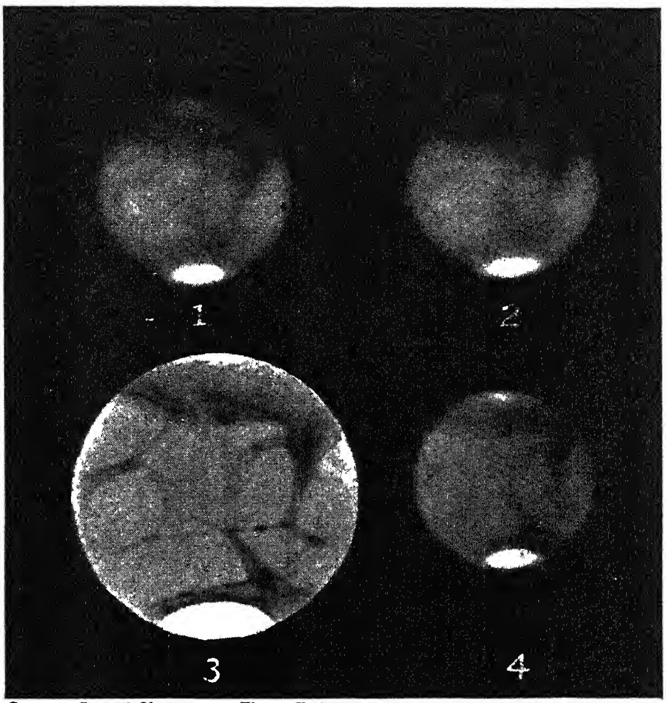
THE GREAT GLOBULAR CLUSTER M13 IN HERCULES

THE BRIGHTEST OF THE GLOBULAR CLUSTERS

THE GREAT STAR CLUSTER OMEGA CENTAURI
This photograph of one of the few clusters visible to the naked eye was taken at the D. O. Mills Branch of Lick Observatory, Santiago de Chile.

The results achieved during the last ten years in extending our knowledge of the planets of the solar system, and in confirming results suspected from visual observation alone, have all been due to our growing ability to understand the messages which their radiations bring. Great as is the advance in this field, it is after all rather insignificant compared to that in our knowledge, due to the same reason, of the stars and of the systems which they form.

A world-famous astronomer is reported to have said that if we fully understood the cause of the variation in the amount of light emitted by a Cepheid variable, we should understand the life history of a star and possibly of the universe. Whether this be true or not, it is at least true that the discovery by Miss Leavitt, of the Harvard College Observatory, of the fact that the median photographic magnitudes of the Cepheid variables in the smaller Magellanic Cloud are very closely correlated with their periods has enormously extended our knowledge of the size and structure of the visible universe. This period-luminosity law for Cepheid variables was found by Harlow Shapley to be true for variables in globular clusters, as well as for those scattered around the Milky Way, thus confirming the suspicion that the cluster variables are true Cepheids and at the same time certifying to the universal validity of the period-luminosity law. The validity of the period-luminosity relationship being established, it is necessary only to know the distance and hence the sun-power of at least one Cepheid variable of known period and the period-luminosity curve will then tell us the sun-power of any other Cepheid of known period. By means of this relation we can find the distance of any Cepheid variable whose period and average brightness is known.



Courtesy Lowell Observatory, Flagstaff, Ariz.

MARS, FEB. 9 AND 10, 1916

Images 1 and 2 are direct photographs; 3 is an independent drawing of the planet; 4 is a photograph of this same drawing made through the large telescope, as were the direct photographs of Mars. Comparative studies of such observations as these examples, demonstrate the existence of the "canal" network on Mars.

The globular cluster Omega Centauri and several of the other brighter clusters were each known to contain a number of Cepheid variables. From the period-luminosity relation Shapley was able to find the distance of these clusters. Knowing the distance of the cluster and its apparent size, he could then find its actual diameter. It turned out that the actual diameter of each globular cluster whose distance was known, is the same. Assuming then that all globular clusters are the same size, we only need to photograph the one whose distance is desired and compare its image with that of another cluster whose distance is known and we can at once obtain the distance of the new cluster. Both images must be made with the same instrument on the same plate and with the same exposure. For instance, if the image of the new cluster has a diameter one-third as

great as that of the image of Omega Centauri, then the distance of the new cluster is three times that of the Omega Centauri cluster. Dr. Shapley obtained the distance of some of the nearer clusters by two other methods besides that involving the use of the period-luminosity relation for Cepheid variables, and the results substantially agreed.

There are about seventy known globular clusters and their distances are vast beyond all conception, the nearest one, Omega Centauri, being so far away that the light of it reaches the earth 21,000 years after it leaves the cluster. The distance of the farthest known globular cluster is more than ten times as great.

Glory of the skies as seen from a planet in a globular cluster

The globular clusters are isolated systems of stars in which, as the name implies, the whole system is contained in a spherical region of space of limited dimensions. Imagine, if you can, a sphere having a diameter of one hundred light-years. In this sphere are from 50,000 to 100,000 stars as bright or brighter than our sun, with perhaps also many more fainter stars besides. A sphere of such size as to contain our sun at the center, and its ten nearest stellar neighbors, at the center of a globular cluster contains 15,000 stars, the faintest of which are about four times as bright as the sun. The stars are more and more closely packed as we proceed from the outside of the cluster to the center.

Do not, however, get the impression that they have little space in which to move and are in danger of constant collisions. Each star is separated from its nearest neighbor by a distance that it takes light about ten months to travel, or fifty thousand times the distance between the earth and the sun.

Imagine the earth revolving around a dwarf star at the center of one of these clusters, one would see in the night sky at least 15,000 stars as bright or brighter than Venus at its best. Is it not possible that on habitable worlds circulating around some of the suns in these clusters may have developed higher types of being than man? What arrogance on the part of man to assume that he is now the highest product of creation.

When we contemplate one of these globular systems of suns, in which each of the thousands of stars of the cluster is in incessant motion, back and forth through the cluster, in such perfect order that the general arrangement of the stars in the cluster remains always practically the same, we stand amazed at the sublime beauty and wonder of it all.

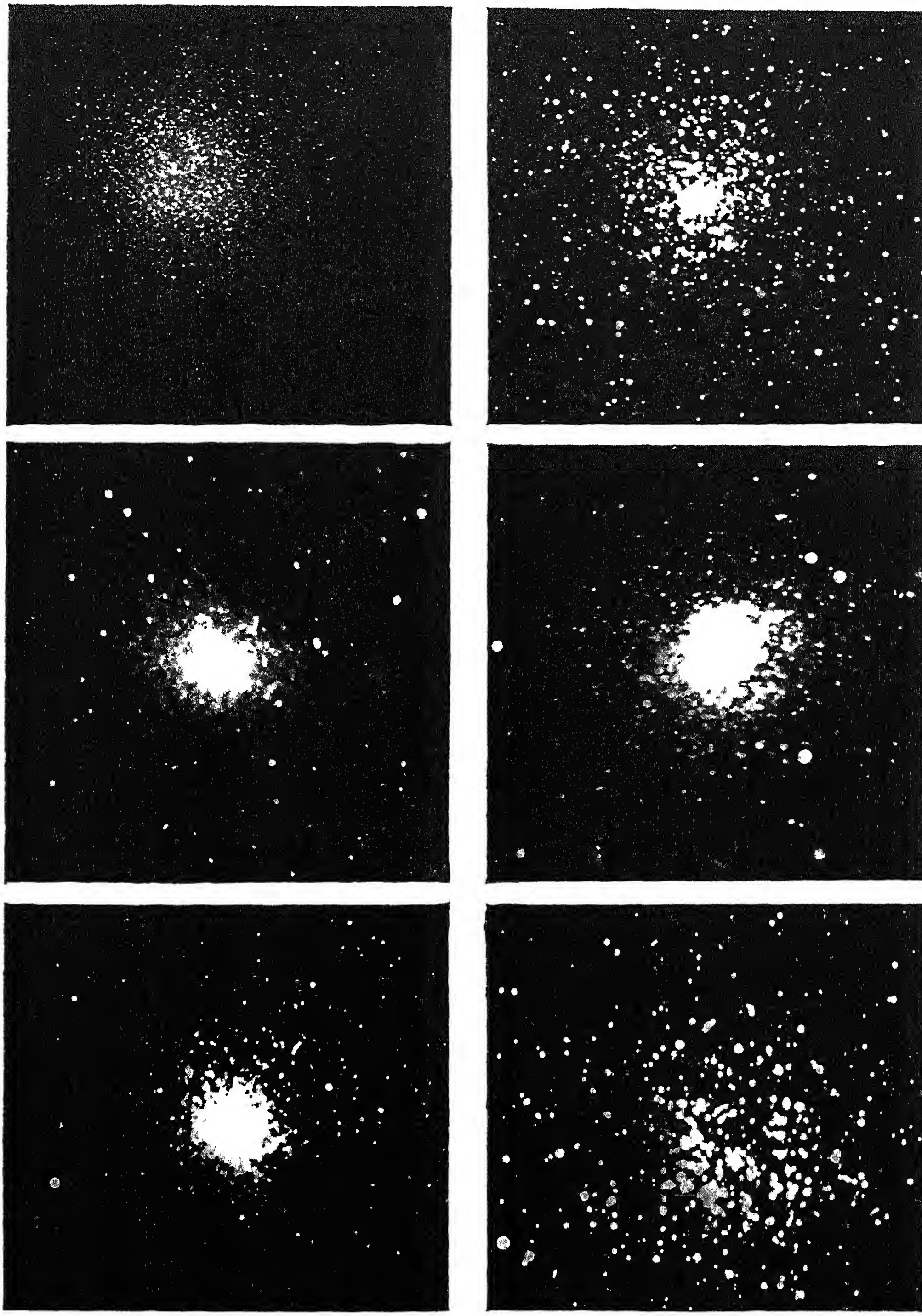
Spiral nebulæ now known to be extra-galactic systems of stars

Using the big Hooker telescope for photographing the Great Nebula in Andromeda, known as M 31, also another beautiful spiral nebula in Triangulum known as M 33, E. P. Hubble recently discovered numerous variable stars in both of them On further investigation he found many of the variables to be Cepheids, and that they obey the period-luminosity relationship. He was justified then in using this relationship to determine the sun power of the variables, and, from this, their distance—which comes out to the amazing value of about 900,000 light-years. This astounding distance is confirmed by the apparent brightness of novæ or new stars, a number of which have been observed in each of these nebulæ.

Some astronomers had suspected for a good many years that the spiral nebulæ were distant galactic systems of stars, Milky Way systems, having dimensions comparable with the galaxy or Milky Way system of stars of which our sun is a member. This new evidence secured by Hubble confirms this suspicion and makes it practically certain that M 31 and M 33 are two of our nearest neighbors among extra-galactic systems.

It is always harder to get a disinterested view of ourselves than to see others in such light, and to see our own galactic system thus is no exception to the rule. Some astronomers believe it to be considerably larger than either of these near neighbor systems, but others incline to the view that the Great Nebula in Andromeda is about the same size as our own. At any rate, the

STAR CLUSTERS

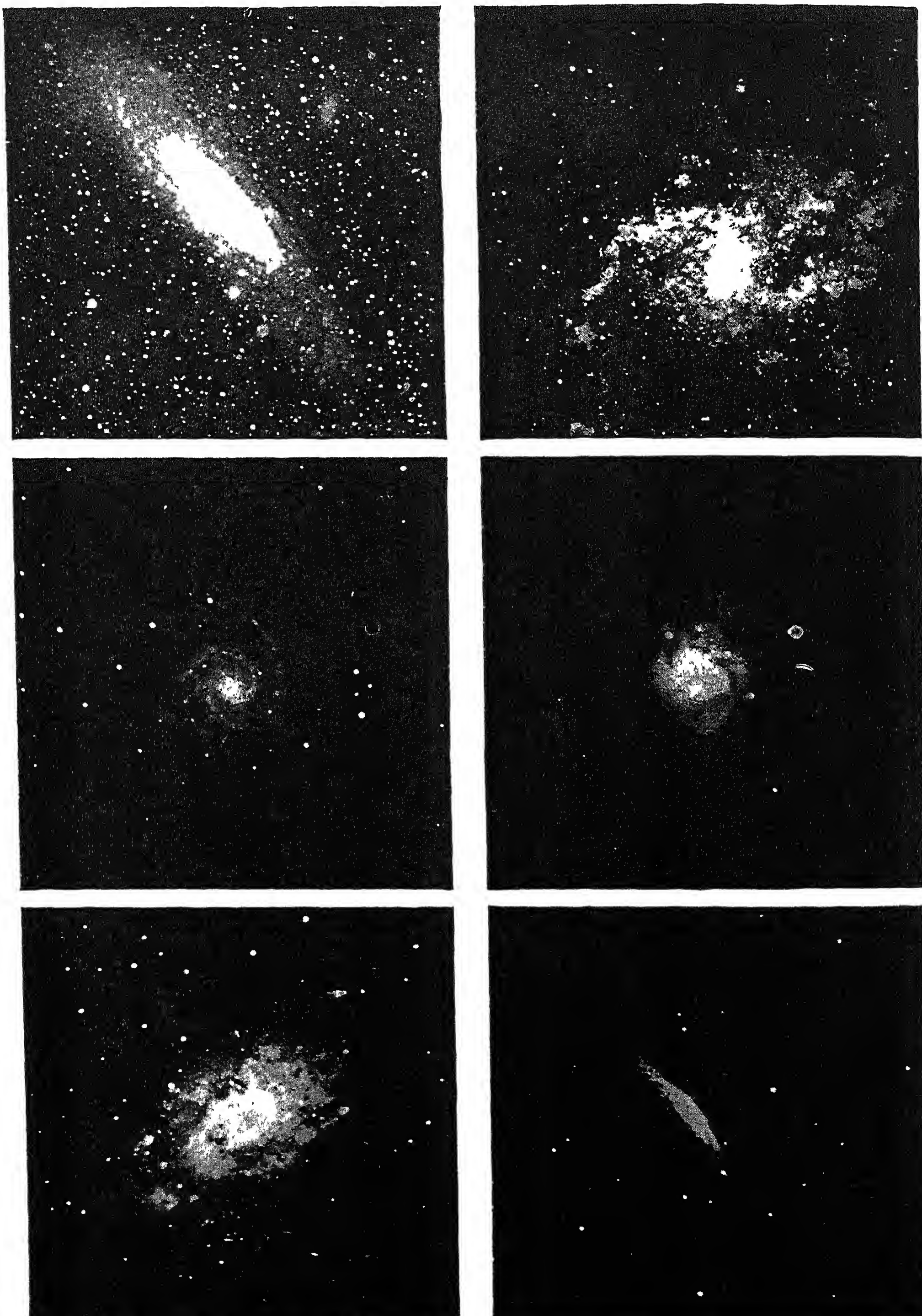


Omega Centauri (Lick)
M 14, Ophiuchi (Roberts)
M 62, Scorpii (Harvard)

M 15, Pegasi (Yerkes)
M 2, Aquarii (Roberts)
M 11, Antinoi (Harvard)

These photographs were taken at Lick, Yerkes, Roberts and Harvard Observatories.

NEBULÆ



The Great Nebula in Andromeda
M 74, Piscium
H.V 44, Camelopardi

M 33, Trianguli
M 77, Ceti
H.I 200, Leonis Minoris

Andromeda Nebula is a galactic system whose larger diameter is about 50,000 light-years, and the spiral in Triangulum is a galactic system whose larger diameter is nearly 20,000 light-years.

It is estimated that we could photograph about five million of these extra-galactic systems with some of our larger reflectors, and while we have only determined the distance of two, besides the Magellanic Clouds, we might possibly get data to obtain the distance of a few more with instruments now available, and are sure of many more when larger telescopes are constructed. Shapley suspects that some of the spiral nebulæ that have been photographed with the Hooker telescope are at distances of the order of one hundred million light-years.

Groups of galactic systems or super-galaxies, each also in motion

In some places in the sky we seem to see clusters of extra-galactic systems or, if we like, a super-galaxy. Both Shapley and Hubble have independently estimated that such a super-galaxy, covering a region a little more than ten degrees in diameter in Virgo and Coma Berenices, is at a distance of about ten million light-years. Each of these galactic systems is itself in motion among the rest, just as our sun is in motion with respect to the stars of our galaxy. In the same way that we find that our sun is moving among the stars about us in the direction of the line to a point near the present position of the star Vega and with a velocity of about twelve miles a second, so we find that our whole galactic system is moving in the direction of a line to the star Alpha Cephei, with a velocity of two hundred fifty miles a second.

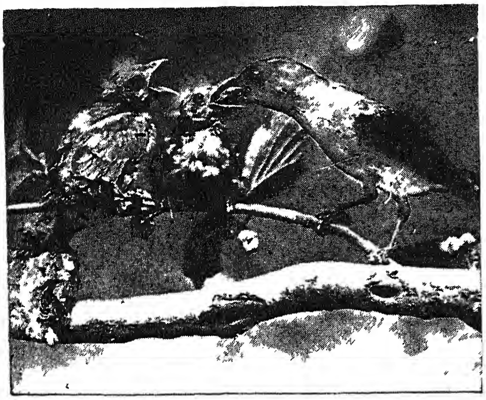
Stars laboratories for the study of matter not reproducible on earth

If now we turn from the contemplation of such vast systems of stars as our own galaxy, or even the globular clusters, to consider the constitution of the stars themselves, we are no less amazed at the revelations of the past few years.

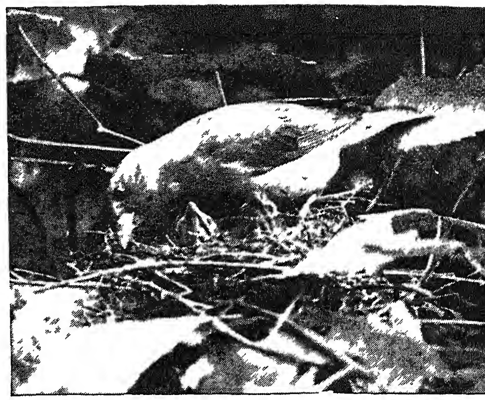
The masses of Sirius and his companion were fairly well known soon after the companion was first seen by Alvan Clark in the year 1862. A good deal of extremely arduous physical investigation in the laboratory, as well as careful investigation with powerful telescopes and spectrographs, has been necessary to determine the size of the companion of Sirius. As soon as we know the mass and the size of a star, we can find its average density. The sun has an average density nearly one and a half times the density of water, but the companion of Sirius has an average density of fifty thousand times the density of water, or about twenty-five hundred times that of gold. This result was obtained as early as 1914 but we could not then believe what seemed so impossible. Ten years later, when we understood better the constitution of matter, we could believe the evidence brought us in messages from the stars.

This gives just a glimpse of how the stars and other heavenly bodies are laboratories in which we can study matter in states which we cannot reproduce on earth.

BIRDS OF THE "AGE OF SPARROWS"



MALE SCARLET TANAGER FEEDING YOUNG



FEMALE SCARLET TANAGER INSPECTING NEST

A GOLDFINCH'S NEST AND EGGS

FEMALE ROSE-BREASTED GROSBEAK AT NEST

WHITE-WINGED CROSSBILL

CARDINAL ON FEEDING LOG

MALE INDIGO BIRD

The illustrations in this chapter are from photographs by A. A. Allen.

OUR COMMON BIRDS III

Flycatchers, Larks, Crows and Jays, Starlings, Blackbirds and Orioles, Sparrows and Finches, Tanagers

DULL FLYCATCHERS AND GAUDY TANAGERS

THE true flycatchers, or tyrant birds (family *Tyrannidæ*), are confined entirely to North and South America, where over 400 species are found. The European flycatchers belong to a very distinct family (*Muscicapidæ*) differing, among other ways, in being true singing birds, while our American flycatchers lack the vocal structures typical of true song birds. As a result, none of them have what are called true songs, although many of them, like the kingbird, are noisy, and a few, like the wood pewee, have very sweet whistles.

The majority of the flycatchers live in the tropics, but among them are numbered some of our best known birds, including, in addition to the kingbird and pewee already mentioned, the phœbe, the crested flycatcher and the least flycatcher. They are mostly small dull-colored birds with typical flycatcher structure and habit. Their bills, for example, are broadly triangular, wider than high at the base and armed with stiff bristles at the corners, efficient structures for snapping passing insects from mid-air. They sit more erect than most birds, usually on a dead branch or other exposed perch from which they can survey the country and dart out after passing insects.

Their nesting habits show considerable variation. The phœbe builds a bulky nest of mud and moss on the cliff or under the bridge, the kingbird one of roots and wool in the orchard, the crested flycatcher chooses a hole in a tree, and, for some unaccountable reason, invariably includes the cast skin of a snake, while the pewee constructs a shallow compact affair saddled on a branch, and always covers the outside with lichens to make it inconspicuous.

Many of the tropical flycatchers and some of the species of our own Southwest are showy birds and often have the broad bill or other parts specialized to a ridiculous extreme. The vermilion flycatcher is of a most brilliant red with darker wings and tail, and the scissors-tailed flycatcher is largely white with a light gray back and scarlet patches on the head and beneath the wings, and the outer tail feathers are greatly elongated, seven to ten inches in length.

All of the flycatchers are insectivorous and extremely beneficial birds The kingbird has been said to destroy honey bees about apiaries, but investigations have shown that the few bees which it does eat are usually drones, and in all other respects he is a most useful bird, particularly about the poultry yard, for he is the self-appointed policeman of the district. No crow or hawk can approach without arousing his ire and being promptly driven off.

The pewee and the phœbe, and all the others, are invaluable allies, particularly because of the large number of moths which they destroy, the larvæ of which, like the cutworm and the tent caterpillar, are potential armies of destruction for the agriculture and the forests of our country.

Being so largely insectivorous, the species which inhabit northern United States are naturally highly migratory, and with the failure of their food supply and the approach of winter, the phœbe is the only one which remains in the United States north of southern Florida. The others cross the Gulf of Mexico or the Caribbean Sea to Central America and northern South America.

PHŒBE

PHŒBE AT NEST

ACADIAN FLY-CATCHER

KINGBIRD

WOOD PEWEE AND YOUNG

The Larks

Although over 225 members of the lark family, including species and sub-species, have been described, there is but one species in North America, the horned lark, all others being found in Europe, Central Asia and the plains of Africa. The North American species is widely distributed from ocean to ocean and from Mexico to Alaska, but is most abundant in the Mississippi Valley. It is a permanent resident wherever found, except in the northern parts of its range, but its non-migratory habits and general adaptability have brought about a great deal of variation in birds living in different parts of the country, as many as twenty geographic races having been recognized. The bird, for example, found along the Atlantic Coast in winter and nesting in Labrador and the Hudson Bay region is the common horned or shore lark. The bird of the Mississippi Valley, New York and western New England is the prairie horned lark, while further west we find the pallid, ruddy, scorched and dusky horned larks. All, however, are so similar as to be indistinguishable except by a specialist.

Although the horned lark is the only native species, the skylark is found in Oregon and on Long Island, but it has been introduced from Europe. It has not multiplied very rapidly but it still seems to hold its own and sings with all the fervor of its European brothers. The meadowlark, which is even more abundant than the horned larks, belongs to an entirely different family, the blackbirds (*Icteridæ*), and will not be considered here.

Larks, in general, are sparrow-like birds with small rounded bills, rounded tarsi and greatly elongated hind toe-nails. The American horned larks are easily distinguished from any of the sparrows by the curious black markings about the face and the little tufts of erectile black feathers on the head. They frequent open farming country and prairie land, where they run along ahead of one in the road or mount into the air with a cheerful whistle. They feed largely upon the seeds of weeds except during the nesting season when they consume a great many insects. In some localities, especially in California, complaints are made against them because of the quantity of seed wheat which they consume. Undoubtedly considerable damage is done which could easily be averted by drilling the wheat. Certainly it is a most near-sighted policy that allows these birds to be shot or driven off, because their attacks upon the insects are much needed, and as soon as they commence nesting they destroy great quantities of grasshoppers, white grubs, cutworms, chinch-bugs, weevils, etc At other times of the year they are of great value in consuming obnoxious weeds like foxtail and quack grass, pigweed, bur clover and corn cockle.

The horned larks begin to nest very early in the spring — and often their nests are overtaken by late snows. The nest itself is placed in a depression in the sod with no protection whatever, but the olive or grayish speckled eggs are nevertheless quite inconspicuous even when left uncovered. The young birds are also protectively colored and are able to run from the nest when but a week old.

During the breeding season the mates perform aërial evolutions that quite equal those of the skylark in daring, if not in melody. Mounting upward on an immense spiral, the bird ascends until nearly lost to sight. Then, poising for a few moments and breaking into song, it takes a thrilling dive toward the earth, closing its wings and dropping like a plummet, and threatening to dash itself to pieces, but it finally catches itself when within four or five feet of the ground, and gracefully alights. In former years, especially in California, larks were netted in tremendous numbers and sold in the markets of the larger cities as game birds, but today, because of their economic value, they are deservedly protected by law.

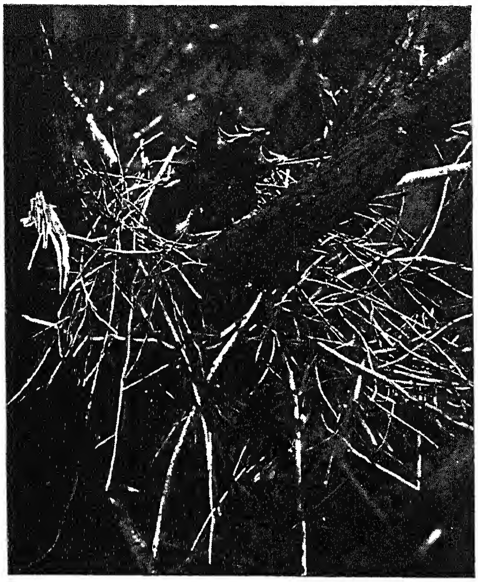
Crows and Jays

Sometimes given first rank among birds because of their intelligence, the crows and jays, together with the ravens, magpies, and the European jackdaws, rooks and choughs, constitute a familiar family (*Corvidæ*). There are about 200 species found all over the world except in New Zealand, twenty-one of which occur in North America. All of them make interesting but mischievous pets and can often be taught to articulate a few words, but in their natural state they are hated by agriculturists and feared by other birds.

All members of the family have stout, heavy bills with thick tufts of bristles at the base concealing the nostrils, strong legs and toes adapted for walking and perching, and strong rounded wings. Our American crows and ravens are uniformly black with metallic reflections, but the jays and magpies are brilliantly colored, blues, greens, blacks and whites predominating. Crows and ravens are further characterized by short square tails, while jays and magpies have long graduated ones.

CROWS AT A WATER HOLE IN WINTER

All species are omnivorous feeders, taking nuts, fruit, grain, insects, crayfish, fish and the eggs and young of other birds.



YOUNG CROWS ARE ALWAYS HUNGRY

Whatever is most easily secured always suits the taste of the crows and jays, and for this reason they are often of considerable value during insect outbreaks because at such times insects are the most easily secured food and they feed upon them to the exclusion of everything else.

A BLUE-JAY AT A FEEDING STATION

But when eggs or grain are more easily secured than insects they may do considerable damage.

The jays are mostly woodland birds and the damage which they do is largely confined to destroying the eggs of smaller birds. They are important factors in the natural dispersal of nut, oak and fruit trees but, like the crows, are also responsible for the wide distribution and constant recurrence of poison ivy. The blue-jay is the commonest species throughout eastern North America, the Canada jay or "camp robber" throughout the north country, the Steller's jay throughout the West and the California jay in the Pacific Coast region. They are noisy birds, traveling in small companies except during the nesting season, and they delight in mobbing a waiting hawk or a sleepy owl. At times they are good mimics and frequently bring consternation into the ranks of smaller birds by suddenly bursting in on them with the call of a dangerous hawk. Jays nest early in the spring, building rather bulky nests of sticks lined with rootlets and laying grayish or greenish spotted eggs.

Crows are much more destructive than jays because they combine with the thieving, egg-destroying habits of the jays a greater size and bolder habits. Thus they often come into the poultry yard, like hawks, after young chickens and regularly feed about corn and grain fields. The damage that they do in the grain fields, however, is largely paid for by the numbers of harmful insects which they destroy. Many times it has been shown, when they have been thought to be pulling the young corn, that they have been merely after the wire worms working about the roots. In the meadows they destroy large numbers of white grubs and grasshoppers, and, near woods, fields frequented by them have been cleared of army worms while adjacent fields have been entirely denuded by the worms. On the whole, however, although crows are scarcely deserving of protection, yet certainly bounties should not be offered for them. They are such wary birds that they are well able to care for themselves and in no danger of extinction even in the most settled country. Because of their wariness, they are usually easily frightened

from the cornfields by the ordinary scarecrow or strings stretched across the fields. Every few days these frightening devices should have their positions changed so that the crows do not become accustomed to them. In extreme cases, a gun fired occasionally in the general direction of the crows will be sufficient to keep them afraid of the scarecrows. A familiar method of protecting seed corn from them is to coat it with coal tar at the time of planting.

The fish crow, which is a smaller species found along the Atlantic coast region, is even more destructive to small birds than its larger relative. It is less wary, often flying through city streets or walking about park lawns, and its high nasal "cah-cah" sounds like the voice of a young common crow before it has left the nest. The raven, larger than the crow, is found throughout the Northern Hemisphere but is more a bird of the forests and wilder areas. With the clearing of the forests in eastern North America the raven has been entirely replaced by the crow.

The Starlings

Until 1890 there were no starlings in North America. At that time sixty were released in New York City and forty more in 1891. From these hundred birds have descended the thousands that now swarm over most parts of eastern United States and the Middle West. There are about sixty species of starlings — family *Sturnidae* — native to Europe, Asia and Africa. As with the house, or English, sparrow, America was warned against the starling by European ornithologists. The warning came too late, and we now have permanently established here a bird that can do far more harm than the English sparrow.

It is true that studies of the starlings' food throughout the year show that economically they do much good. But this domineering bird replaces much more valuable birds, such as blackbirds, swallows and flickers, by driving them away from their nesting sites and feeding grounds. Since starlings withstand our northern winters, they are already on hand in the spring, and they can appropriate the best nesting sites and feeding grounds before the migratory birds return.

Starlings nest in small openings, on ledges or under eaves of buildings, in bird boxes or in hollow trees. They will drive off flickers and nest in the holes that the flickers dug for themselves. Five to seven white or pale-blue eggs are laid; often three broods a season are raised.

After the nesting season, starlings gather in enormous flocks, whereupon they either roost with the blackbirds in the marshes or gather about steeples or cupolas. Before retiring and upon arising the entire flock performs a series of aerial maneuvers with all the precision of trained soldiers. In the air starlings can be recognized by their strong, direct flight, their pointed wings and square tails. On the ground they walk like blackbirds but have longer bills, which are yellow during the nesting season. Their much shorter tails are quite distinctive. During the fall and winter their iridescent black feathers are spotted with buff, but this wears off as spring approaches.

Allan D. Cruickshank — National Audubon Society

A starling — insects' enemy; bully to other birds.

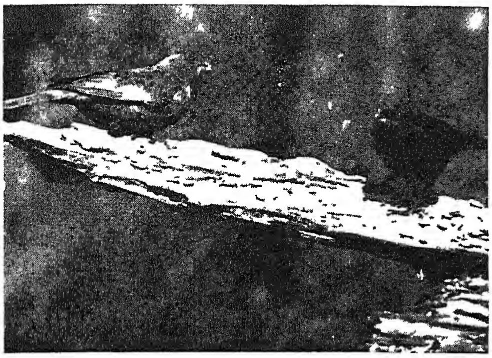
PAIR OF RED-WINGED BLACKBIRDS ON CAT-TAILS

The Blackbirds

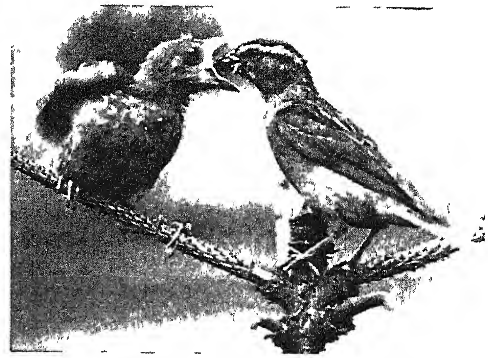
If birds were classified by their colors or by their habits the family (*Icteridæ*) of the plain blackbirds and brilliant orioles would have to be divided into many, so divergent are the various members which compose it. There are over one hundred and fifty species in the family, all of them confined to the New World, but only nineteen are found north of Mexico. Some of them are dull-colored and some are very strikingly marked, but all are similar in having strong perching feet, tails of twelve feathers, pointed wings, and bills that extend backward, dividing the feathers of the forehead and leaving the nostrils exposed and not concealed by bristles. To this family belong the well-known blackbirds, many of which show brilliant red or yellow patches, the orioles which are perhaps our most gorgeous birds, the black and white bobolink with his finch-like mate and the aberrant meadowlark, which has taken on the streaked back pattern of the sparrows and the terrestrial habits of the true larks As a family they are nearly omnivorous feeders, taking seeds, insects and fruits During the summer they all feed upon insects and are extremely valuable birds, but during the fall the many species of blackbirds assemble in large flocks and often do considerable damage.

PAIR OF BALTIMORE ORIOLES NEAR THE NEST

Of the blackbirds the red-winged or swamp blackbird, the cowbird and the grackle, or crow blackbird, are the commonest and best known. The redwing hangs its nest in the bushes or reeds of the marshes but after the nesting season visits the uplands in large flocks to feed The female is streaked gray and black and lacks the scarlet shoulders of the male. The cowbird is found about pastures following the cattle. It builds no nest of its own, but like the European cuckoo lays its egg in the nest of a smaller bird and lets that bird hatch the egg and rear the young. The male is black with a brown head, the female uniformly grayish. The grackle is larger than either of the two former, uniform black with metallic reflections, and with a long tail that it holds boat-shaped when it flies. It walks around the lawns in our parks, nests in a variety of locations but usually in the tops of tall evergreens, where in the fall large flocks often assemble to roost. During the spring and summer blackbirds



PAIR OF COWBIRDS ON FEEDING LOG



YOUNG COWBIRD FED BY CHIPPING SPARROW

are almost entirely insectivorous and are very beneficial, but during the late summer and fall when they assemble in flocks they change to a vegetable diet and in some places do considerable damage to grain fields.

The orioles are almost entirely insectivorous, although they are fond of fruit and sometimes do a little damage to cherries and early pears. They never travel in flocks, however, and the damage they do is negligible. The Baltimore and orchard orioles in the East and the Bullock's oriole on the Pacific Coast are the best known. They are famous for their deep, pensile nests, marvels of bird architecture. They have loud ringing whistles that make our woodlands and shaded roads musical during the late spring and summer, but their song period is short and they are among the first birds to stop singing in July.

The meadowlarks and the bobolinks are perhaps the most valuable birds of the open fields and are worthy of every protection even though the bobolinks do assemble in large flocks on their migrations and do a little damage in the southern rice fields. The meadowlark has a loud, clear, plaintive whistle that varies in different parts of the country, while the bobolink gives us a rare jumble of whistles, warbles and banjo-like notes that seem to fairly burst with exuberance as he hovers over the meadows.

On the whole the family *Icteridæ* contains some of our most brilliant, most musical and most beneficial species, whose structure and habits are so varied as to make them a most interesting study.

BRONZED GRACKLE FEEDING ITS YOUNG IN THE NEST

NEST OF RED-WINGED BLACKBIRD IN AN ARROW ARUM

The Sparrows

The sparrows, finches and buntings constitute the largest family (*Fringillidae*) of birds. Over twelve hundred species and subspecies inhabit the world, except for Australia, but they are most abundant in the Northern Hemisphere. In North America north of Mexico over ninety species have been recorded and in the eastern United States approximately fifty.

Sparrows are generalized in their structures rather than specialized. They are now the dominant birds of the world. The strong conical bills of the sparrows, although modified for crushing seeds, are at

The impressive and beneficial meadowlark (right).

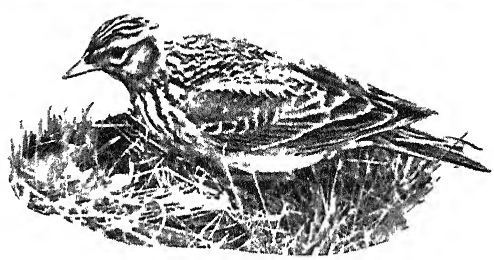
The horned lark (below) dwells in open country.

L. A. Fuertes — U. S. Fish and Wildlife Service

the same time sharply pointed to enable them to pick up the smallest insects. The sparrows are correspondingly versatile in their feeding habits so that, while in fall and winter they feed almost entirely upon seeds, during the summer they consume great quantities of insects. They are, therefore, among our most valuable birds, both for their consumption of weed seeds and for their destruction of insects.

The typical sparrows are rather dull-colored, brown and gray birds, usually heavily streaked to blend in with the pattern of the grasses, for the majority of

L. A. Fuertes — U. S. Fish and Wildlife Service



Eric J. Hosking

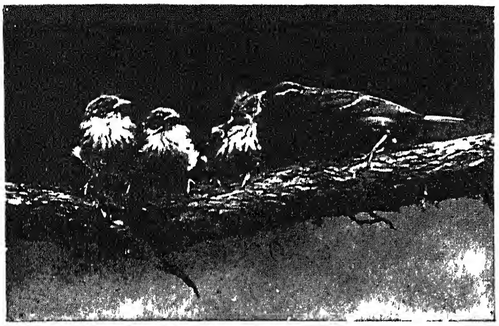
European skylark, made famous by English poets.

them are terrestrial birds feeding and nesting on or near the ground. However, the family includes goldfinches, grosbeaks and buntings, many of which are brilliantly colored. The separation between this family and the most strikingly colored birds, the tanagers, is nowhere too distinct.

Many species have beautiful songs and are well known as cage birds — the canary and European bullfinch being the common examples. Our native sparrows and the grosbeaks and buntings are second only to the thrushes in their musical ability.

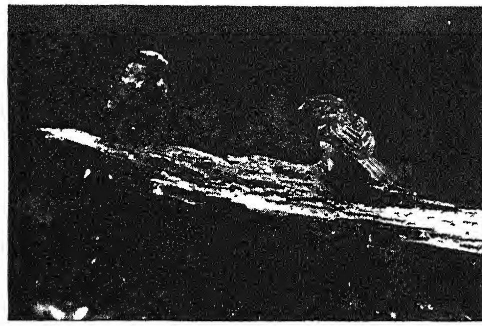
Sparrows build well-formed nests of straws and grasses, lining them with finer grasses and horsehair. Most of them lay bluish eggs more or less spotted brown.

SOME MEMBERS OF A VERY LARGE FAMILY



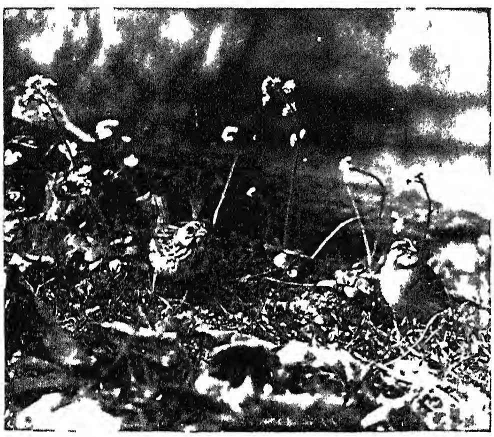
CHIPPING SPARROW FEEDING YOUNG

Young chippies have streaked breasts showing the typical sparrow marking lost by their parents



PAIR OF HOUSE SPARROWS ON FEEDING LOG

The conspicuous black bib of the male is concealed during the winter by gray edgings to the feathers



SONG (left) AND WHITE-THROATED SPARROWS

They have met at a feeding station about the first of May as indicated by the hepaticas and saxifrage in blossom

MALE EVENING GROSBEAK ON FEEDING LOG

A bird of the Northwest that occasionally wanders to New York and New England during the winter

VESPER SPARROW INCUBATING

Commonly called "groundbird" by country boys, it shows white feathers in its tail when it flies.

MALE GOLDFINCH ABOUT TO FEED YOUNG

His crop is full of softened seeds which he will regurgitate into their throats.

all experience matters, that we are different for everything that happens to us. But ordinary language, often inexact in all spheres, is so particularly, flagrantly, persistently inexact in the sphere of the mind, that we very rarely realize the great psychological truth upon which modern students insist. We hear a name, and forget it the next moment or the next day, and say it has "slipped clean out of my mind"; and though sometimes when we hear it we recognize it, showing that something somewhere remembered, often we cannot even recall the fact that we had ever heard it. Each instance we observe, in ourselves or our friends, of the retention somewhere of words, habits or sensations, which appeared to be lost, to be nonexistent, astonishes us, and naturally so, for it is contrary to everyday experience.

The unobliterated record kept by the mind, though sometimes hidden

But the study of the subject shows that we should be astonished no longer. Everyday experience is wrong, as when it positively witnesses the sun moving across the sky. The fact is that nothing "goes in at one ear and out at the other". The brain is between them, and what it has it holds. If the words be properly defined and understood, it is true that we forget nothing.

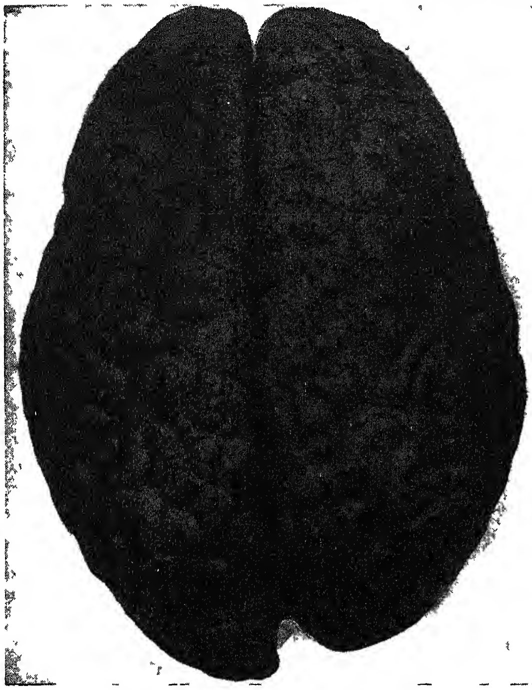
Obviously this does not mean that we can recall every sensation we have ever experienced. In fact, myriads of sensations have occurred in us, and have affected us, which *we*, our conscious selves, have never experienced; they happened too deep beneath the surface of consciousness for us to notice. We can hardly expect to replace in consciousness what never had a place there. Nor does it mean that, though we cannot recall a sensation — say, the sound of a name — we can at least recognize it when it is recalled for us. Often, as we have seen and well know, we cannot; we are astonished at things we see written in our own hand; it is incredible that we can ever have written them; we could swear that we did not — but we did. Plainly, then, the assertion that we forget nothing requires full and proper definition before it can be accepted.

The constant state of change that marks the recording soul

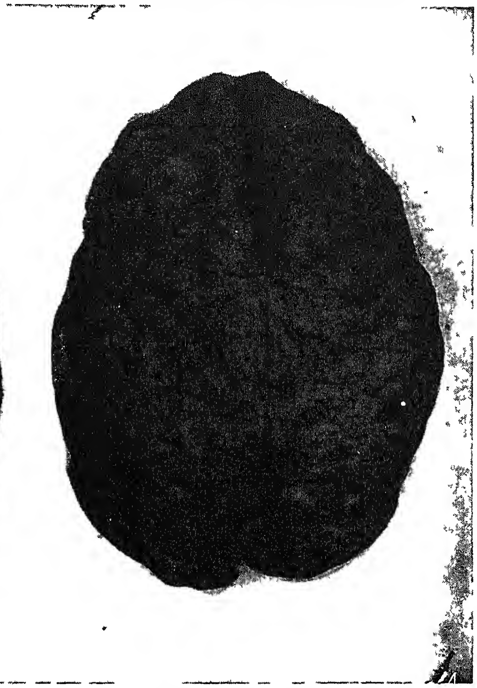
"To live is to change," as Cardinal Newman said long ago, and as Professor Bergson, in his "philosophy of change", insists today. Inanimate things exist and persist, but time, as such, does nothing to them. We say that time does, but we mean that, in the course of what we call time, they are affected, by wind and weather and the worm, or what not. Time in itself does not exist for them; it is only something we invent to measure events by. But "real time", as Bergson calls it, exists in and for the living creature alone, for to live *is* to change, and all the changes of its past are summed up and have their effect at any moment of the life of a living creature. It *is* the sum-consequence of all its past. Time, therefore, is real for it. This is the deepest meaning of memory — a deeper and wider one than is convenient for the ordinary use of the word. This is the meaning which has led certain thinkers like Samuel Butler, author of "Erewhon", and the German biologist, Ewald Hering, to look upon heredity as, at bottom, the expression of the memory of living creatures — memory which means consequence not only in the particular individual, but also in its offspring, so that we are not merely the sum of our own past, but the sum of the whole past of life. All that fascinating department of speculation is beyond our present purview, but it helps us to realize what modern psychologists mean when they speak of memory in its wide sense, and with what interest they study all experience, all sensations, as destined in some degree to determine the constitution, behavior and destiny of the individual forever afterwards.

This, then, is the tremendous fact which we have to face when we study the results, the future fruit of our sensations, both our conscious and our sub-conscious sensations, both those of external things, and those of our own doings. But it must not be misunderstood in the fashion, only too familiar to students of human thought, which breeds hopelessness, despair, a feeling of impotence in the clutches of the past.

HEALTHY AND DISEASED HUMAN BRAINS



BRAIN OF HEALTHY INDIVIDUAL



BRAIN OF IDIOTIC CHILD

Photos courtesy Jelliffe and White

A DISEASED CONDITION OF THE CORTEX OF THE BRAIN

Evil experiences irrevocable but not necessarily fatal

That is a perversion of the truth, and of the doctrine here laid down as the deepest teaching of modern psychology. When we allude to religion in dealing with it, that is because religion deals with the conduct of man, and therefore cannot be left out of any true or useful discussion of psychology And, at once, what we have been saying must have reminded the reader of familiar teaching associated with religion. For there are some schools of religious thought which have always perceived the lasting importance of all experience, which is what we here assert, but have thence reached conclusions to which we must demur. It is not here asserted that all evil experience is not only irrevocable, but, in itself, fatal. It is not here admitted that what we call sin, including forbidden experiences of the senses, is something which, being permanent in its consequences, is necessarily disastrous in its consequences. Psychology teaches, sternly and benignly, that all experience has consequences; but it can make no distinction between what morality calls good or evil experience in this respect, and it cannot possibly say that what was, at any time, evil or good remains so unchanged, somewhere in the individual record.

The denial by psychology of the "guilty stain" of theology

That is the idea which is expressed in the Recording Angel, and all those forms of religious teaching which conceive of a man's acts and experiences as being permanent in the sense that they are separately, indelibly, *unchangeably* recorded, somewhere It is the idea of a "stain upon the soul", which nothing can efface; and which has led immense numbers of men and women to commit suicide in religious melancholia, because they saw no hope of freedom from the stain.

Now, all this is precisely and utterly what modern psychology denies. Modern psychology asserts that to live is to change unceasingly, and that to live is itself an act of mind, which underlies all vital processes. Mind is a living thing — and the mind of man accordingly changes, in "real time", as a consequence of all that it does, feels, perceives, thinks and suffers. Thus everything matters. Every deed reacts upon the doer; every experience — of a landscape, or of having had a large meal — tells in its due degree upon the personality, the self, the Ego, as upon the body. The living man is pushed forward, so to speak, by the whole of his past, which is ever being added to, and is ever changing him.

The ever-changing flux of the everlasting mind

But while this doctrine agrees with the teachings of the past in asserting the importance of *all* experience — for we really forget nothing — it evidently denies and utterly contradicts the idea of a man as a kind of permanent statue, upon which there can exist an irremovable stain. *That* idea is of a kind of living being that is a contradiction in terms, for it is evidently not alive, but dead, like a statue. The living mind cannot be permanently "stained", for it is alive, it is in flux, ever changing, like a stream of the ocean, taking in all manner of experiences, absorbing them into itself, changed and different in consequence; but immeasurably the opposite of what some theologies have conceived — a fixed, changeless, dead *thing*. on the outside of which, or in a book about which, certain facts of behavior are recorded. The behavior, the good or bad thought, the harmless or evil pleasure, the deed, the desire, the emotion, the work, the play — these are not something to do with a man, something about him, something to add up in a column under his name, something important because irrevocable and recorded in indelible ink in a book; these *are* the man; these have entered into the living substance, the "mind", the "self" of him. He *is* the sum and expression of all his play and work and thoughts, true and false, and feelings and intentions and sorrow and joy.

Everything matters, then; we agree with those theologians; but it matters in an immeasurably deeper and more infinite and momentous sense than they imagined.

How we ourselves are the lasting record of our past

Each of us is his own recording angel, and the book in which he writes. But the book is not a diary, with a leaf for a day, in which the "written word remains". The book is alive, it is a fluid book, in which all the writing is no sooner recorded than its identity is gone, for at once the letters flow into all that have preceded them, and the result is a writing which corresponds to no page of the past, and yet comprises the issue and consequence of them all; and that writing is you *now*, but not you when you have finished this chapter or paragraph, for then already your attention, understanding, misunderstanding, assent, dissent, liking or dislike, will have changed you. But because you are you, with your past, your experience, your memories known and unknown to yourself, your identity your personality, the you-ness of you remains; and though you change unceasingly, though you can never return and be again what you were yesterday, and though you must continue to change, here or hereafter, if you are to be a living "mind" at all, yet all the while you will be yourself, and not another, because the whole of your unique past remains, stored up, but not stored up, unrecognizable, but consequent, in *you*.

These are conceptions of the self, of the real nature of man, which have only to be stated to be accepted; and if they involve the relegation of much familiar teaching on great matters to the limbo of puerile folly, the sooner that end is achieved the better, for then we shall be nearer a greater development in religion, which shall be more valuable for man in proportion as it understands him better.

And now we are ready to study the consequences of our sensations, for we have an enhanced idea of their importance, and we have firm hold of a truth which is the beginning of wisdom, and which physiology alone ignores or denies. For we have already seen that a sensation is liable to be a stimulus, and that a stimulus commonly produces a response, a corresponding action which we call a "reflex"; and physiology and psychology have to concern themselves largely with such reflex actions. But their insistence upon the response is apt to lead us to think that no more now remains to be said of the sensation, the stimulus to which the reflex action was the reply. That is an error of the most serious kind, turning us aside from any true understanding of personal development, or of the deep meaning of memory.

No doubt the body and the mind reply to the blow, the caress, the tune, the odor, in some way or another, though indeed there may be no immediate reply; but the memory of the stimulus, and of the response or of the failure to respond, or of the effort by which response was checked — these remain, and have their lasting consequences. Furthermore, a reflex need not be immediate. Physiologists reckon what they call the "latent period" of a reflex, during which nothing appears to happen, though it is true that the response is being prepared.

The latent and reserved responses that may come from early impressions

It lasts, in a given case, for perhaps three-hundredths of a second, they say; but it may last a lifetime, and on his dying bed a man may respond to sensory experiences which he learned at his mother's knee, or in very different places. Properly understood, the period of latency matters not; reply is reply, whether by return of post or after "the night brings counsel", or whether a man does not "get back" at his enemy for a generation, when at last he may then have the chance to ruin his son. The truth remains, and is illustrated alike in every case, that we forget nothing; that everything of which we have sensation affects ourselves always, not by some plastered substance adhering without, but by internal change and development, somewhat after the fashion of a kaleidoscope, though no material image can do justice to the case of the mind's life.

Let us, then, here leave on one side the questions of response, action, external reply to sensations, on the ground that they must be studied later, when we know more about the "self". Will, desire, pur-

pose, resolution, consistent striving — all these facts of the mind, showing themselves in muscular acts of a thousand kinds, must not be considered yet, the assertions of nineteenth century materialism notwithstanding, for the sufficient reason that we must first try to learn more about *that*, thing or person, material or spiritual, which or who wills, intends or strives.

The something in us that no materialism can ever explain

Many a man, it has been said, has "too much ego in his cosmos", but it will not do to leave out the ego altogether. Our first business now is therefore to try to follow our sensations, of all these kinds we have studied, and see what happens to them "inside", and whose sensations, if anybody's, they are.

Materialism says they are nobody's sensations. When we speak of the self, or the soul, it replies that there is no such thing. It is content to say that when the eye is punched the fist projects, and that, in reality, is just the same as the case of a pugilist's punching-bag which, when struck, returns; the response is mechanical, obeys mechanical laws, and there is no more need to attribute an ego to the pugilist than to his punching bag.

The fact was that physiology was so interested in tracing the external response as to forget all the rest. In point of fact, if you strike a punching-bag, it may return and hit you, once, and immediately, and that is all; but if you strike the pugilist, you may find that he strikes more than once, or not at all, that he bears resentment or contempt, that he remembers, perhaps when you thought he had forgotten. Something is there which you cannot see, and which the punching-bag lacks.

The wonderful multiplicity of our simultaneous sensations

Each one may be his own subject and object of observation here. Observing ourselves at any given moment, we realize that we are the subject — note that irresistible form of words — of a variety of sensations. Any moment of waking life will serve for an illustration, and we are all familiar with instances which serve to show the multiplicity of simultaneous sensations. At a meal, in the theater, in church, in the country or the city, we are being assailed, so to speak, by sensations of many contrasted kinds. You watch the play or the opera, and you simultaneously see and hear; the "after-dinner mint" you suck is giving you sensations of taste and smell, your right hand clasps precious fingers, and your left side is uncomfortable owing to the contact of a fat stranger. Your constrained position gives you various kinæsthetic sensations from muscles and joints, and you are frightfully thirsty.

Specimen sensory sensations while listening to a play

This will serve as an illustration. Here is a technical description of the facts: "At any moment of waking life the state of one's consciousness, in so far as it is sensational — and every state of consciousness is largely sensational — is due to a multitude of stimuli playing upon the sense-organs within and on the surface of the body, and exciting, indirectly through the sensory nerves, a number of different specific psycho-physical processes in the sensory motor arcs of the various areas of the cerebral cortex. Each of these excites an elementary quality of sensation of greater or less intensity, and all these are fused with various degrees of intimacy to form the complex sensory background of consciousness in which, by successive efforts of attention, we can discriminate different qualities."

Psychical states that visit us at the play and are not sensory

Observe that the state of consciousness is not wholly sensational. As you listen to the play, and are yourself played upon by the various sensations described — and by many more, for you hate your neighbor's loud breathing, and someone is talking behind you, and there is a blessed (or disagreeable) draught, and your shoes are tight, and you feel as if you wanted to blow your nose, and so on — you are also the subject of many other psychical states which are not sensory.

You like or dislike the play, you wish you were somewhere else, you are astonished at the contrast between the play and what you had heard about it, you are annoyed because the actor you came to see is not playing, you are wondering why you never came to see such a fine play before, you want to destroy half the audience for laughing in the wrong places, you hope your companion is enjoying it, you mean to come again at the first opportunity, and so on literally *ad infinitum*.

But even if we try to simplify the problem by leaving out of account all these deeper and subtler psychical components of it, we have to face this amazing variety, contrast, opposition of mere sensations at any given moment, and ask ourselves how and where and in what or whom they manage to exist simultaneously? We are undeniably conscious, through and by them all, of ourselves. We have a unity; we are not a mere heap of "sensory-motor arcs", or assemblage of psycho-physical processes. I am here, and I feel such and such, all at once. But we have seen that the brain consists of a number of separate centers and arcs, that one of these may be thrown out of action and the rest remain intact, that their working, say, of eye and ear, is independent; where is the seat of this unity of consciousness, this first-hand unchallengeable feeling of the "self", the single subject of all these sensations?

No area of the brain where the sensations are pooled

Time was, and that not long ago, when the physiologists were sure that, somewhere in the brain, there must be a place or center, a *sensorium commune*, or common resort, of all sensation, where every separate item of our sensations was somehow registered, and so fused with all the others as to account for this unity of consciousness. Various parts of the brain, the function of which was not known, have been labeled accordingly, in the hope of finding a material place which should explain (and explain away) the Ego. But the increase of physiological knowledge has steadily dogged the steps of these interpreters. Wherever they settled, and said, "Here is the center where all sensations are pooled, giving us the illusion of unity we call the 'self'", inquiry has shown that the area in question had a definite function of its own, equilibration, touch, taste or what not; and in fact, there now remains *no part of the brain whatever* on which this theory can find rest for the sole of its foot. The evidence of neurology, and of the exact study of the individual senses, and the law of Müller, which shows how each sensory center is specific, yielding only its own kind of sensation, however it be stimulated — all these have disposed of the theory of "physiological fusion of sensations", either in a *sensorium commune* or in any other way. And the soul returns.

The fusion of all these sensations having been proved to be not physiological, for the brain keeps them all apart, and there is nowhere where they can be pooled, it is impossible to deny that it must be psychical.

Here are the words, not without some historical interest, written by Dr. William McDougall, in 1905, at the very beginning of that advance of science beyond nineteenth century materialism, which is now triumphing on every hand, above all through the influence of M. Bergson.

The recovery by science of the idea of the soul

"We are compelled to admit, or so it seems to the writer as to many others, that the so-called psychical elements are not independent entities, but are partial affections of a single substance or being; and since, as we have seen, this is not any part of the brain, is not a material substance, but differs from all material substance in that, while it is unitary, it is yet present, or can act or be acted upon at many points in space simultaneously (namely, the various parts of the brain in which psycho-physical processes are at any moment occurring), we must regard it as an immaterial substance or being. And this being, thus necessarily postulated as the ground of the unity of individual consciousness, we may call the *soul* of the individual."

After the strange aberrations of the recent past, the study of the senses has thus brought science back to its senses. *You* do exist, after all. Indeed, it is not *mal à propos* to remember that, after all, the best that logic could do, in the nineteenth century, for the definition of matter was in terms of mind, for John Stuart Mill defined matter as a "permanent possibility of sensation", which is to refer the existence of all the outer world to That which feels.

Thus we may say that the soul returns; and the refutation of materialism by physical science, which has divested matter of its materiality, is complemented by the advance of psychological science, which has worked right through the brain, without encountering the soul, only to find the soul more necessary than ever.

The need for believing not only in the mind's sensations but in the mind itself

Let us now hark back, two or three centuries, to a former discussion of the great question before us. That discussion culminated, for the time, in the famous "Essay on the Human Understanding", which was written by Dr. John Locke, whom we commonly regard as the father of modern psychology. In that great book, Locke set himself to study the doctrine of "innate ideas", according to which such ideas and beliefs as those of God and immortality are innate in all of us, and are not derived from without us, or in any way received through the channels of sensation. Locke came to the conclusion which our study of sensation will have led us to accept, almost wholly, that "Nothing is in the mind that was not first in the senses." In contravention of the theologians and scholastic philosophers of his time and before it, Locke declared that all our ideas, without exception, are derived from sensation and reflection on past sensations; in other words, all our ideas are derived from individual experience, and the senses *are* the "gateways of knowledge".

But what we have just been studying will make us a little uncomfortable in the presence of Locke's dictum, as it stands.

Nothing in the mind but its sensations — except itself

It almost reads as if sensations *were* the mind, which would practically mean that *the* mind was a myth. Hence we are ready to receive with gratitude the famous brief addition which Leibnitz made to Locke's words, thus: "Nothing is in the mind that was not first in the senses, *except the mind itself.*" On every ground that addition is necessary. In the preceding pages we have seen one — that the unity of consciousness, in the presence of multifarious and simultaneous sensations, requires us to believe in a "something", "the mind itself", *of* which those sensations are the sensations. A totally different field of inquiry leads to the same conclusion.

Sensations are everything, nothing is in the mind that was not first in them, Locke said; and thus all that what we call the mind amounts to is a paper upon which sensations inscribe what they will. But the study of heredity, and of the natural differences between individuals, has shown us what is indeed so evident — that the mind is something more than a blank or vacuum to be filled, and is a real, distinct, unique something in each of us, which has characteristics, powers, tendencies earlier than all experience. Experience, indeed, is *its* experience; *it* was there first. True, in a sense, is the assertion that nothing is in the mind that was not first in the senses, but truer still is the addendum, *except the mind itself.*

The soul returns; and its return is the leading fact of the history of psychology during the last generation or so of human thought. The senses go to furnish, or contribute to furnish, its very stuff; they give entry to its nourishment and its building material, but the "City of Mansoul", of which they are the gates, is more than any or all of them put together. Yet let us suppose that this is simply the swing of the pendulum back from one extreme to the other, and that modern psychology humbly begs pardon, and yields place to the teachings of the past upon the soul, all and sundry.

The deficiency in language for the expression of modern ideas of the mind

It is just the risk of this misunderstanding that has deprived modern writers of half their necessary vocabulary.

Even such a term as the "Ego" has its disadvantages, though we cannot do without it. Rightly, no doubt, the philosopher begins with it, and can indeed assure us of its real existence without reference to those modern researches into the functions of the brain which we have lately reviewed. Long ago Descartes laid down the doctrine, "*Cogito, ergo sum*" — I think, therefore I am. It is impossible to begin except with the "I", and therefore it is impossible to reach any other conclusion than that it exists.

But we are not to delude ourselves into imagining that our problems are now all solved — that there is no further need to prosecute a science of psychology. No, indeed; the soul is alive, and all the problems of the living soul, and of every living soul, remain. It changes from moment to moment, since to live is to change; it is infinitely sensitive, learns everything, or may, and forgets nothing; it has its ups and downs, its states of happiness and distress, hope and fear; its parts war with one another, struggle and survive, or are repressed, and there is no discharge in that war; as for its ultimate destiny and such supreme questions, we have much hard, plain inquiry on lower planes to deal with first; but at least we shall proceed to investigate the emotions, the instincts, the intelligence, the memory, the will, with hope of success, having first satisfied ourselves that there is a psychical something, which is the subject — or the ruler — of all these states.

The failure to pitchfork the soul out of human nature

And though this assurance may seem scarcely worth stating to some, they will only be those who have never examined it. The rest of us, who have been through the inevitable stages of inquiry and discovery, and renewed inquiry, and who know what the teaching of science seemed to indicate only thirty years ago, in the dawn of physiological psychology, will prize aright the assurance of today, that however often science, falsely so called, may seek and seem to pitchfork the Soul out of Human Nature, the substance of which *is* Soul, it will surely return.

EXHIBIT OF SOME SURPRISING PRODUCTS OF CELLULOSE

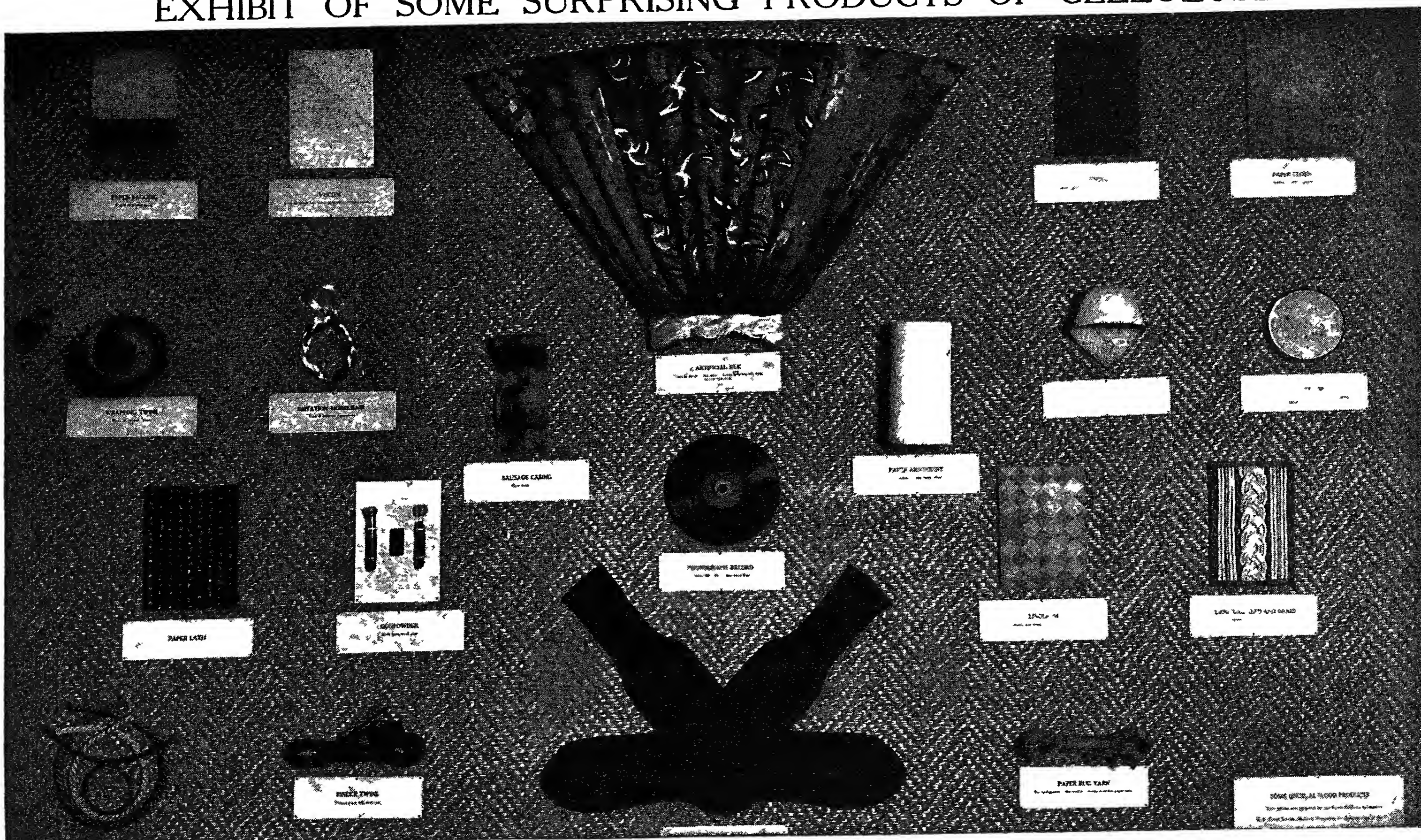


Photo Forest Products Laboratory, Forest Service, U S Dept of Agriculture

Paper bagging
Wrapping twine
Paper lath
Paper rope
Viscose
Imitation horsehair
Gunpowder
Binder twine
Sausage casing
Artificial silk
Phonograph record
Socks
Paper absorbent
Shingle
Paper webbing
Linoleum
Paper rug yarn
Paper cloth
Wood flour
Furniture reed and braid

CELLULOSE AND ITS MANY USES

Some of the Applications Made of It by
Man for His Comfort and Convenience

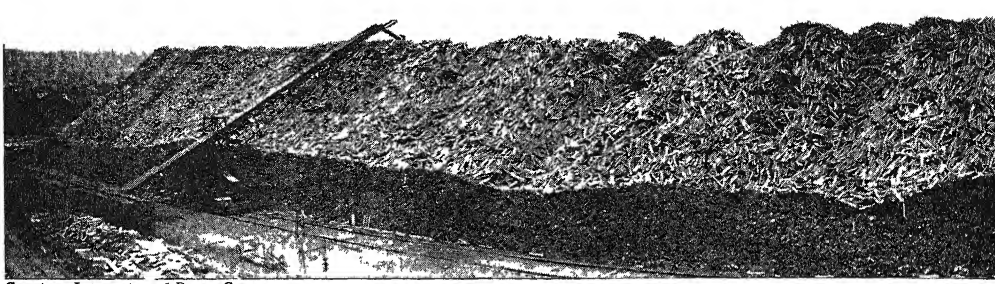
ANOTHER MARVEL OF THE CREATIVE CHEMIST

AS a result of the wonderfully painstaking studies of the botanist and biologist with his microscope, it has been demonstrated that all plant tissues, from a blade of grass to the giant sequoias of California, are comprised of small units or cells, very much as a house is made up of rooms. Thus, in the vegetable kingdom, we have shanties, bungalows, ornamental residences and office buildings and incidentally, the kitchen arrangements and general plumbing system enjoyed by most trees and plants would put a large number of our own apartment houses to shame. The envelope or partitioning wall for these cells is composed of a material called "cellulose", which the inquisitive chemist has analyzed and found to consist of the elements, carbon, hydrogen and oxygen, in the atomic proportion indicated in the formula $C_6H_{10}O_5$. At least one-third of all plant substance, when dry, is made up of this material.

Animal tissue is likewise composed of cells, but the cell walls of animals are constructed of proteins, which, these same chemists tell us, contain carbon, hydrogen and oxygen in entirely different proportions from that found in cellulose and, in addition, contain a large amount of the element, nitrogen. A thorough search of the animal organism fails to reveal cellulose anywhere in its make-up, the production of this material being left entirely to plants. Yet plants can and do produce proteins, which would seem hardly fair under the circumstances but has been so ordained by nature.

Proteins and cellulose are quite different, so much so that when a tree dies its household arrangement can, with considerable ease, be kept nearly intact for some time, whereas upon the death of an animal the cells usually fall apart and disintegrate rapidly unless strenuous efforts are made to the contrary. Certain portions of the animal, like the hair and bone, are much more stable than the flesh. Proteins, as a rule, have a decided tendency to become swollen and to go into solution when immersed in water, are quite susceptible to the attack of bacteria and are more or less easily oxidized on exposure to the air. On the other hand, cellulose is very resistant chemically. It is insoluble in water, is not readily decomposed by water, even though boiling, is relatively stable toward air, and very few bacteria can attack it successfully. Cellulose is also resistant toward the action of a large number of the milder chemicals, such as laundry soap, acid or basic dyes, various bleaching agents, writing inks and the like.

It is largely these resistant qualities of cellulose that permit of its great industrial use by man. It is true that man cannot digest cellulose, so it is no use to him as a food. In this connection, the digestive fluids of the herbivorous animals, in particular the goat, are more successful in getting cellulose into solution and so assimilable by the system But man makes houses, furniture and tools of wood, and so we have our great lumber industry, which in order of magnitude ranks fourth in the United States.



Courtesy International Paper Co

FORTY-SIX THOUSAND CORDS OF WOOD

The wide-spread use of cotton, in the form of cloth and fabric, is familiar to all, and cotton, those marvelous hairs produced by the cotton plant in its boll to protect the seeds, is 95 per cent pure cellulose.

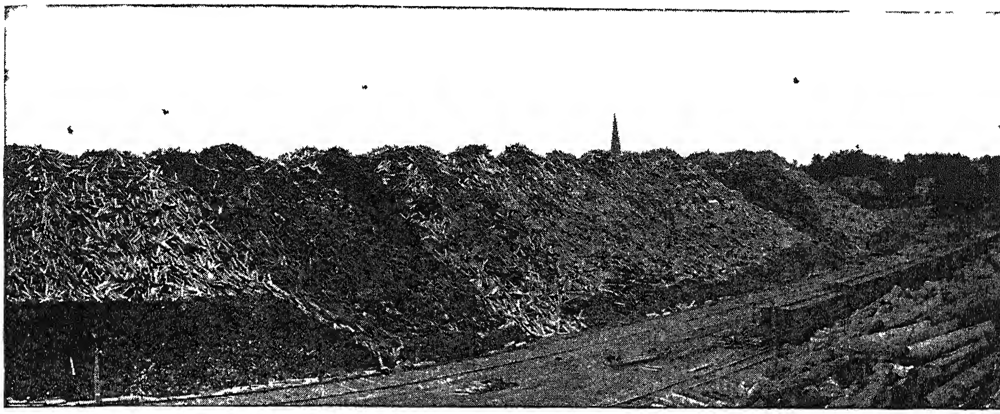
From the cellulosic components in the stalk of the flax we obtain the material to make linen, from jute and ramie, the material for rope and twine. In addition to the cheap and abundant supply of natural cellulose and to its excellent wearing qualities, the relative mechanical strength of cellulosic material, as compared with its weight, is indeed remarkable. If, for example, we imagine a cotton thread being unwound from a spool, the unwound portion dangling in space, a length of thread $14\frac{1}{2}$ miles long could thus be released before the thread would break from its own weight. This breaking length for cotton is about four times that of wool and about three times that of ordinary steel wire, but is only three-fourths that of silk.

Perhaps the most important contribution toward the progress of democratic education and civilization has been the utilization of cellulose in making paper. The invention of what is called printing is essentially the inventing of paper Type was known to the Romans, but before type could be utilized as a means for disseminating knowledge, it was necessary to wait several hundred years to obtain a practical paper to print upon.

The cellulose for paper was first obtained from linen and then from a mixture of cotton rags and linen. It is now obtained from wood which is indeed fortunate in view of the enormous amount required. The manufacture of pulp for paper for the United States requires over 5,000,000 cords of wood per year. Spruce and hemlock are the favorite victims. Pine is apt to give trouble on the paper machinery due to the rosin present.

For the cheap grades of paper, for example newspaper, trees are cut into logs some three feet in length, and the ends of these logs are pressed against the wet sides of rapidly moving grindstones. The "mechanical pulp" so formed is "beaten" with water until the fibers have become separated, evened in length, and somewhat softened. The thin water suspension is then run on to the moving wire screen of the paper machine, where most of the water is drained from the pulp by means of suction applied at points under the screen. The resulting mat of tangled and fitted fibers passes in a continuous sheet from the wire into a set of suitable drying rolls and finally through the calendering or ironing rolls where the surface finish is given. Variations in this finish are attained by adding suitable sizing materials, such as glue or rosin, into the beater. The modern paper machines are marvels of precision and efficiency. A speed of 1000 feet of finished paper per minute has been attained by a machine in one of the Canadian mills.

Newspaper is not a very pretty paper. It does look as though it had been thrown together in a hurry and, furthermore, it has a tendency to turn yellow after a week



FOR MAKING PULP FOR PAPER

or so. But all this is not wholly the fault of the paper machine. Wood fibers are not made up entirely of cellulose, there being present, for instance, about an equal amount of a material called "lignin" that is thoroughly mixed in with the cellulose. It is this lignin which renders the fibers difficult to mat in the machine, and which turns the paper yellow on aging. For the production of higher grade paper, book paper and the like, this lignin is removed by cutting the wood in chips and digesting these chips under heat and pressure with a solution of calcium sulphite or caustic soda or alkaline sodium sulphide. Either of these three reagents will dissolve out the lignin and soften the fiber, leaving behind what is called "chemical" pulp. This pulp can then be bleached to any desired degree of whiteness and can be beaten and made up into paper in a machine that is run a little more slowly than for newspaper. If you will examine closely the paper on which this is printed, you can see the result is far from bad. However, due, in part, to the rather severe treatment necessary to separate lignin from cellulose, wood paper is not as permanent as cotton or linen paper.

So far, only those uses for cellulose have been considered that depend upon its natural chemical inactivity. Even in the separation of lignin from wood cellulose in the making of paper pulp, reliance is had upon the cellulose remaining nearly intact while the various impurities are removed.

However, if cellulose is subjected to the action of certain chemical reagents, it has been found possible to transform it into various derivatives of great technical usefulness. The importance of these derivatives is further enhanced by the fact that cellulose, as a starting material, is cheap and plentiful. It can almost be said that wherever the chemist has touched cellulose, it has turned to gold. There are now innumerable cellulose derivatives.

Some of the most important of these derivatives are those obtained when cellulose, in the form of cotton or chemical wood pulp, is treated with various acids. To secure the desired product, however, certain specified conditions must be observed in this acid treatment, conditions which have been determined by the chemist as the result of very careful laboratory experimentation. For example, if cotton be boiled with a dilute water solution of nitric acid and then taken out of the acid and dried, the product will be a white insoluble powder that is of no use to anyone. On the other hand, if the cotton is treated with a cold concentrated solution of nitric acid containing some sulphuric acid, and then is removed from the acid bath, washed and dried, the result is guncotton, one of our most powerful explosives. Though the physical appearance of the cotton has been affected but little, in reality a chemical reaction between the nitric acid and cellulose has taken place, the product being technically termed the nitric acid "ester" of cellulose or cellulose nitrate.

This material is very inflammable, burning with great rapidity and evolving large quantities of hot gases. When this gas evolution takes place in a confined space, such as the breech of a cannon, the result is the forcing of the cannon-ball or shell out of the muzzle of the gun with a tremendous velocity. However, if guncotton, as such, were fired in a cannon, its rate of burning is so rapid that probably the whole gun would burst before the shell could get out at the muzzle and so relieve the gas pressure. So, in order to slow down the rate of burning, the guncotton is dissolved in a mixture of ether and alcohol, or in acetone, to make a plastic mass. It has been found possible to mold this mass into rods or cubes or grains that will burn at any desired speed. The burning is quite complete and sootless and hence the term "smokeless" powder.

Brown Brothers

ALFRED BERNHARD NOBEL, SWEDISH CHEMIST

Guncotton, mixed with nitroglycerine, another powerful explosive, and a little vaseline, gives the high explosive known as "cordite". This material was the invention of Alfred Nobel, the Swedish chemist, in 1878. A number of other high explosives, such as TNT and the various picrates, have been developed in recent years, but cordite was the pioneer in this field. On the fortune that amassed from its invention, Nobel founded the famous prizes which bear his name and which were designed to promote the advancement of civilization and the abolition of all war. This seems almost ironical in view of the fact that high explosives form the basis for modern warfare.

In guncotton the nitration has been carried almost to completion, and the cellulose molecule has combined with practically all the nitric acid groups it is capable of holding. Now if nitration be stopped before completion, the resulting products are the lower nitrates of cellulose or pyroxylins. These materials are much less explosive than guncotton, though still inflammable, and have been put to more humanitarian service. For example, a number of solvents for these pyroxylins have been discovered and the resulting solutions have been found well adapted to a number of everyday uses. Thus, pyroxylin, like guncotton, is soluble in a mixture of ether and alcohol, the resulting solution being commonly known as "collodion". When the solvent evaporates, the pyroxylin is left behind as a smooth, plastic, durable film that is fairly water and weather proof. Accordingly collodion makes an excellent varnish, either by itself or when mixed with resin or gums. It is even applicable to the human skin, and as "new skin" has grown popular for protecting cut fingers and bruises. During the Great War "new skin" was used to allay some of the effects of its more vicious relative guncotton.

By stirring finely divided metal powders, such as bronze or aluminum, into a collodion solution, it has been found possible to give surfaces an attractive metallic finish If the newly lacquered radiator smells suspiciously of ripe bananas, then amyl acetate has been used to make the collodion. This solvent, as well as ethyl acetate, acetone and the like, has largely supplanted the ether-alcohol in making pyroxylin varnishes and lacquers.

If pyroxylin films are formed on heavy canvas, the result is artificial leather, a material that in many ways is more durable and serviceable than hide leather, in addition to being much less expensive.

Courtesy International Paper Co

A BIG LOAD ON ITS WAY TO THE PAPER PULP MILL

The present day demand for this cellulose product for the manufacture of such articles as shoes, purses, traveling bags, upholstery, automobile tops and cushions is enormous and its usage in this connection has proved to be efficient and economical. This material has found wide acceptance in the automobile industry and in many allied fields The universally common practice of artfully coloring and stamping some of these cellulose articles to resemble the natural grain in the skin of a cow, a horse or an alligator would seem to be quite unnecessary in view of the really excellent wearing quality of the substitute. This successful utilization of cellulose has, in fact, been a very happy stroke, for the demand for leather has far outgrown the ability of our animal friends to provide it. Over one-half of the "leather" articles manufactured today are of strictly vegetable origin.

The origin of the celluloid industry and its remarkable development

Another important use for pyroxylin is in the manufacture of camera and movie films, these articles consisting essentially of a coat of sensitized gelatine spread upon a pyroxylin backing. Large quantities of pyroxylin are also consumed in the making of celluloid, an industry that originated in 1863 from the endeavors of John Wesley Hyatt, of Albany, to develop a satisfactory substitute for ivory in the manufacture of billiard balls.

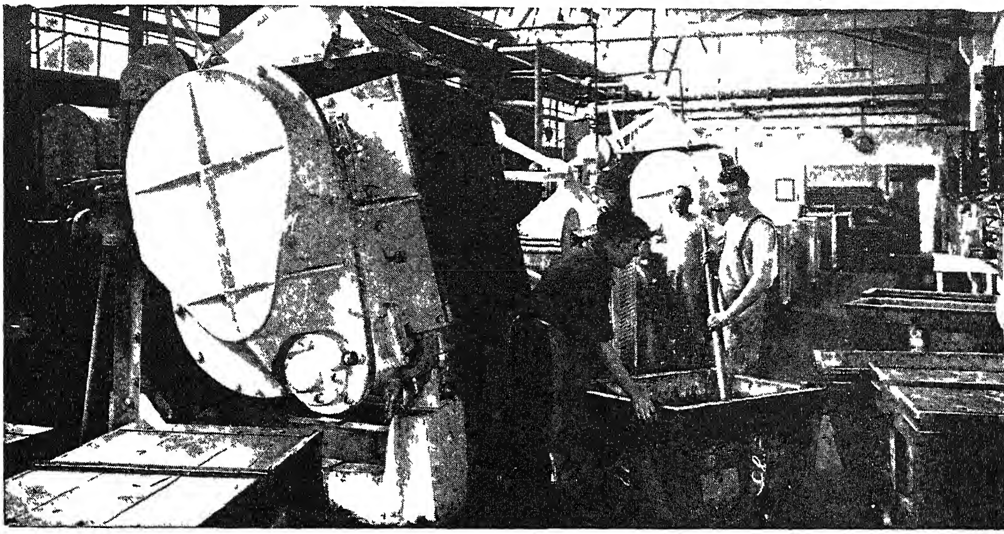
Hyatt was keenly interested in a prize of $10,000 offered for the development of this substitute for ivory, an offer induced by the increasing scarcity of elephants having tusks as big in diameter as a billiard ball. A typesetter by trade, Hyatt had an experience with a bruised finger which led him to appreciate the tough, elastic properties of collodion film Hearing that Parkes and Spiel in England had had moderate success in getting this material into a form that could be molded by mixing it with camphor, he determined to make a few experiments himself.

The two Englishmen named had both used castor oil in order to get a thorough mixing of the two solids, camphor and pyroxylin, with the result that the product did not stand up well under usage. Hyatt, long accustomed to printing-presses, was a firm believer in the efficiency of pressure under heat to produce coherence between solids. Upon mixing the camphor and pyroxylin and putting in a hot press, he obtained a homogeneous solid, which, when hot, was quite plastic and capable of being molded, and when cold was tough, elastic and durable, a material he called "celluloid". For the making of billiard balls celluloid proved disappointing, so Hyatt soon began experimenting with metal balls and developed the ball bearing that has almost revolutionized mechanical engineering. Again, he was disappointed in the matter of billiard balls, and he is still thus disappointed today though more than a hundred important different inventions have resulted from his attempts to solve the original problem.

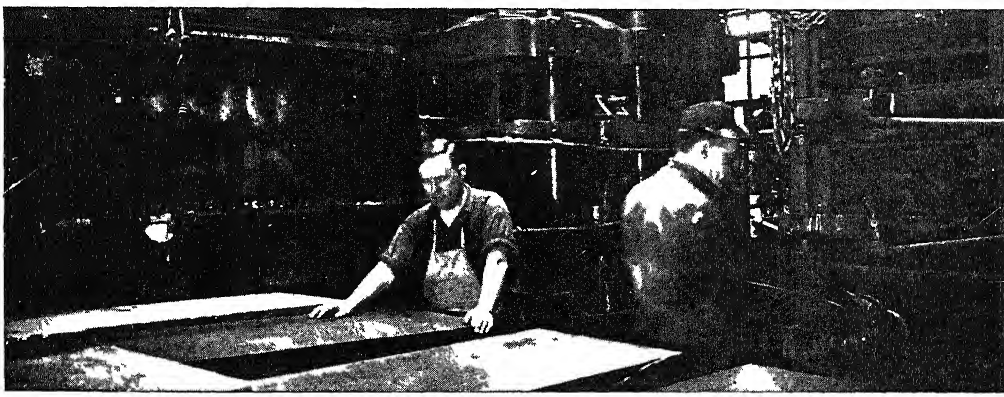
Hyatt did find celluloid admirably suited as a substitute for ivory and bone in a great many articles, and he began their manufacture. The resulting industry has had a remarkable growth. Celluloid, when hot, can be molded, tubed, died, stamped or blown, — when cold, it can be turned, carved, polished. It can be made to resemble ivory or bone in appearance. It does not have the limitations as to shape or size of the bone or ivory, and it lasts just as long and is much cheaper. Today, celluloid is used extensively in making umbrella handles, toilet sets, card cases, buttons, piano keys, picture frames, phonograph records and hundreds of well known articles. It appears under a variety of trade names, such as "fiberloid", "viscoloid", "pyralin", "xylonite" and the like. Celluloid has its disadvantages. It always smells of camphor, it softens when warmed, and it is very inflammable.

This property of easy inflammability is the main objection to the commercial application of pyroxylin. It is possible to de-nitrate this pyroxylin or cellulose nitrate by treatment with ammonium or metallic sulphides, and thus obtain a product that is less inflammable, but the de-nitrated material is not as soluble as the original ester and, accordingly, is not so well adapted for many of the uses of the latter. Consequently, many attempts have been made to develop other soluble esters of cellulose that would have less fire risk. The most prominent of these have been the cellulose acetates made by treating cotton or wood pulp with acetic anhydride. These esters are quite soluble in a number of organic solvents, are non-explosive and are much less easy to ignite. They produce a somewhat more brittle film than the nitrates, but could well be substituted for the latter, except of course to produce explosives, were it not for their relatively high cost. Accordingly, their use has been restricted to certain fields where the specific advantages of the material outweigh its greater expense. During the Great War the cellulose acetates were used extensively in making the "dope" to protect the wings and woodwork of airplanes where low inflammability was an essential.

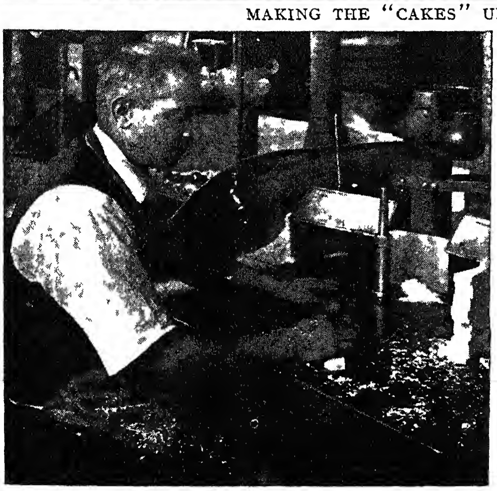
CELLULOSE IN TOILET ARTICLES



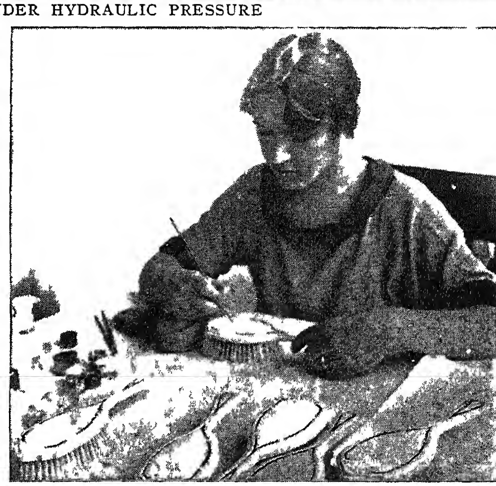
MIXING THE INGREDIENTS



MAKING THE "CAKES" UNDER HYDRAULIC PRESSURE



ROUTING A HAIRBRUSH GROOVE



DECORATING AND PAINTING IT

Pyroxylin is the basic ingredient of pyralin, the DuPont de Nemours & Co.'s trademark for their cellulose material for the making of toilet and other articles. Pyroxylin is made by nitrating tissue paper — that is, shredded tissue paper is immersed in a mixture of sulphuric and nitric acids, after which the acid is wrung out of the paper by means of a centrifugal wringer. The acid treated paper is a nitro-cellulose.

Cellulose reacts readily with sulphuric acid, but the resulting cellulose sulphates are not used as such, since these esters are soluble in water and are easily decomposed by the same. If a sheet of paper be dipped into moderately concentrated sulphuric acid, the surface of the paper becomes gelatinized, due primarily to the formation of cellulose sulphates. If the paper is then removed from the acid, washed and dried, these sulphates are decomposed, leaving a very strong paper possessing a smooth, hard, translucent surface that closely resembles parchment. In fact, most of our so-called "parchment paper" is now made in just this very way, the more expensive sheepskin being reserved for very particular cases or "fussy" people.

This general principle of giving to cellulose a smooth uniform surface is the basis of the important "artificial silk" industry, an industry in which large fortunes have been lost and made. The term "artificial" is misleading in that the protein material evolved by the silkworm is not reproduced, but rather cellulose is worked into such a form that it *resembles* silk, primarily in that it reflects light in the same way as does silk. In "artificial" indigo or "artificial" perfumes, exactly the same compound produced by nature is made in the factory.

A silk thread owes its high luster, its "silky" appearance, to the fact that the silk fiber is round, with a translucent surface, and in spun silk a large proportion of these fibers lie parallel to each other. Light is reflected evenly and uniformly from such a set of regular surfaces, and the inherent luster of the individual fiber becomes visible to the naked eye. Now the individual cotton fiber likewise possesses luster if one views only a single spot on this fiber. But the cotton fiber is a flat twisted ribbon-like affair, and when spun these ribbons lie in a tangled mass. These irregularly placed surfaces of the cotton yarn reflect light in all directions, and the result is light interference or dispersion and the loss of all luster by the yarn. It is the physical oondition of the fiber emitted from the spinneret of the silkworm that the artificial silk manufacturer seeks to reproduce with cellulose.

This condition is attained to a pronounced degree by subjecting cotton to the process known as "mercerization". In 1844, John Mercer, a calico printer of Lancashire, England, found that when cotton yarn is passed through a 30 per cent solution of caustic soda, the yarn shrinks in length by about 20 per cent and increases in strength by about 50 per cent. It is said that a French firm offered Mercer $200,000 for his patent rights, but important development of this process did not occur until 1900, when Lowe in England demonstrated that if "mercerizing" treatment was applied to cotton under tension, not only were the shrinkage and increase in strength obtained, but also the yarn assumed a permanent luster. Apparently, the caustic gelatinizes and softens the cellulose fibers, and these, under tension, tend to round out and to straighten out as far as possible. On withdrawing from the caustic, washing and drying, the fibers harden permanently to this condition. The whole process is thus somewhat similar to that of parchmentizing previously described. In recent years, the commercial importance of this new development has been fully realized, and the process of mercerization come into general use.

Inasmuch as mercerization deals with a pre-formed fiber that has already been spun into a thread, the creation of regular surfaces and the straightening out of the fiber along parallel lines, conditions required for high luster, can at best be only partially attained. A greater degree of success has been gained by getting the cellulose entirely in solution form, and forcing this solution through small holes or dies into a bath that will precipitate the cellulose. The result is an almost instantaneous solidification of the stream coming through the die and the formation of a continuous round filament of cellulose that can be wound on bobbins and spun in any desired way. The operation thus approximates closely that carried out by the silkworm itself and the result is a strong thread possessing a luster fully equal to, or even better than, that of the natural product, only this thread is composed of cellulose and not protein.

While considering the more important uses to which man has put cellulose, some mention should be made of two other industries that depend upon a much more drastic transformation of the natural material than any hitherto described.

If wood chips or sawdust is subjected to prolonged digestion with various mineral acids, the cellulose is converted almost entirely to glucose or grape sugar. This substance, though somewhat useful in itself, can be fermented to give alcohol, and some industrial alcohol is now being made from sawdust. The older method of securing alcohol by the fermentation of grain is apparently capable of supplying the existing demand, but it is commonly thought that alcohol may possibly be called upon to act as a motor fuel when the petroleum wells begin to run dry. In such an eventuality, recourse must be had to wood and plants, and the cellulose process, in order to supply the enormous amount of material required.

When wood is burned in air, the result (neglecting the heat evolved) is a total loss as far as man is concerned. However, when wood is heated in large retorts with no more air present than can be avoided, a process called "destructive distillation", a number of valuable products are obtained. For example, one cord of wood yields 50 bushels of charcoal, 11,500 cubic feet of fuel gas, 25 gallons of tar, 10 gallons of "wood" alcohol (not to be confused with grain alcohol) and 200 pounds of acetate of lime. From this last, it is possible by simple procedures to make acetic acid and acetone. Up to the time of the Great War, these two very important chemicals were obtained only in this way, but when the enormous demand arose for acetone for the manufacture of smokeless powder, a process was developed whereby both acetic acid and acetone could be made from calcium carbide, a product of the electric furnace, and the success of this process has seriously upset the wood distillation industry.

From the foregoing pages, some idea may be obtained of the manifold parts that cellulose plays in our modern civilization. It has been possible only to touch upon the outstanding applications made by man of this remarkable material to his own comfort and service. A material, endowed by nature with phenomenal powers of resistance toward the elements, man has constructed of it a shelter, a covering, a means for perpetuating knowledge and understanding. As a vast source of raw material, he, guided by chemical research, has converted it to countless derivatives that have been found useful in nearly every phase of human life, derivatives that fulfil new functions and purposes, that substitute for other materials obtainable with more difficulty or functioning less satisfactorily. And now that man has acquired an adequate understanding of the chemical nature of cellulose, he has been able to make even fuller use of this wonderful natural material.

"Cellophane" which has become in recent years a popular wrapping material is exactly like viscose rayon in its composition, and it differs only in that in its last stage of preparation it is extruded through a slit rather than through a hole, and thus is formed into a flat sheet. In 1912, Dr. Jacques Edwin Brandenberger, a Swiss textile chemist, was producing thin, flexible cellulose film of the general type used today, for which he coined the distinctive name "Cellophane." Little commercial advance was made during the World War, but at its conclusion, Brandenberger, with an improved product, obtained the backing of France's largest rayon company. In 1923, the du Pont company acquired the exclusive rights to manufacture "Cellophane" in North America, and soon after, a subsidiary of du Pont's was formed which began active production. At the time of its introduction here, a pound of "Cellophane" cost $2.65, which meant, for example, that a wrapper for a loaf of bread would cost over two cents. At first confined to wrapping luxury merchandise, it became more and more popular as a result of lower costs, its natural advantages as a transparent and protective covering, and improvements such as moisture-proofing. Several modern factories are now required to make enough of this decorative, protective material to satisfy the demand.

The great difficulty has been to get the cellulose properly into solution so that it could be precipitated out again in a strong and serviceable form. The first patent was granted to Comte H. de Chardonnet in France in 1884. He nitrated cotton to form pyroxylin and dissolved this material in ether-alcohol, our old friend collodion. The precipitating bath was either water or simply air, the ether and alcohol being dissolved or evaporated. Later, it was found necessary to pass the thread through a calcium sulphide solution to de-nitrate the cellulose in order to prevent an untimely cremation of the unfortunate wearer of the finished products.

It was found that cellulose could be dissolved in an ammoniacal cupric oxide solution, the precipitating bath in this case being a solution of caustic soda and glucose. Or the cellulose might be dissolved in a concentrated solution of zinc chloride, the precipitating bath being alcohol. In 1892, Cross and Bevan, two English chemists, discovered the "viscose" process in which cellulose, in the form of sulphite pulp, is treated with caustic to form alkali-cellulose-hydrate. On digestion with carbon disulphide, this substance forms a cellulose xanthate that is soluble in water. Weak acids precipitate the cellulose from this solution as cellulose hydrate. Later, these same chemists also discovered the acetate process, in which, as previously described, cellulose is converted, by treating with acetic anhydride, to cellulose acetate which is soluble in a number of volatile organic solvents.

The term "artificial silk" was soon replaced by the name "rayon" when manufacturers and the public found that this new product of the test tube was not a substitute for silk, but a different and distinct material which could claim a place in the commercial world on its own merits.

There are four types of rayon: nitrocellulose, viscose, cellulose acetate, and cuprammonium. All four use purified cellulose as the basic raw material, but the chemical process which the cellulose undergoes before the final product is reached differs for each type of rayon. As compared to silk, all rayons have a low elasticity, stretch out of shape and dry that way, and when wet lose much of their tensile strength; however, rayons clean more easily, do not hold dirt as tightly as natural fibers do, resist abrasion well, and can be made up in any desired luster or dullness. White rayons do not turn yellow with age as white silks do, nor are they as badly affected as silk by light and perspiration. Each type of rayon has its particular properties. Acetate rayon is superior in some ways to viscose rayon, particularly in the matter of strength when wet. Its high insulating capacity and imperviousness to water render it valuable for wrapping electric cables and wires. The fact that these rayons react differently toward different dyes makes it advantageous to interweave them, and then to dip them into the dyes each will take. Viscose rayon is as lustrous as natural silk, and though it does not wear as well is far less costly.

MAKING THE DESERT BLOOM

Irrigation Works, Ancient and Modern, the Means of Saving Millions of Acres and Lives

ATTEMPTS TO SUPPLY THE LACK OF RAIN

ONE of the marked differences between a savage and a civilized man is that the one trusts to nature while the other works for what he needs. It was agriculture, the labor of cultivating food plants, that made man civilized. The first of the ancient peoples to become great nations were farmers. We must not, however, place too much blame on the savage peoples of that period because they did not take to agriculture and so become civilized. They remained savages, not because their natures were necessarily bad, but because the soil in the countries they inhabited was not suited to agriculture. The civilized nations became great because they were fortunate in having settled on lands that were fertile.

Thus it was that the Egyptians were among the first people to become civilized. When their early ancestors settled in the Nile valley they found the soil along the banks of the river wonderfully fertile. Far up, near its sources, there are some big lakes which act as reservoirs in storing the water and regulating its flow. Because of this the rise and fall of the Nile is almost as regular as clockwork. On almost the same day each year, in the fall, the waters begin to rise and spread slowly over the adjoining fields in vast, placid lakes. Then the flood begins gradually to recede. By June the river is back in its regular bed and the drained-off fields along the banks are left with a thick cover of sediment, or mud. This the early Egyptians would plow with their forked logs and plant wheat and barley. The crops would then grow and ripen without a drop of rain.

On account of these fertile lands producing such rich crops the Egyptians became a very prosperous people. Prosperity gives people leisure; the time in which to think and develop their brains. With such a surplus of food products everybody had more than enough and part of the people were able to devote themselves to other occupations. Some took to studying the forces of nature about them, a system of writing was invented, and learning and civilization followed.

With their intelligence once awakened, it was only natural that such a people should seek means to improve conditions about them. Already they had learned to realize that nature is most bountiful to those that assist her. Probably, too, the population was increasing and more food products than could be raised along the banks of the river were needed.

By this time the learned men among them had made certain observations along their great valley. They saw that the river, flowing down the center, was slightly higher than the level of the desert away from the banks on either side. For ages the Nile water had deposited its sediment along the banks until they had been raised and formed a sort of very wide embankment on each side, not unlike the levees which are built along the Mississippi, to keep the river from overflowing.

Imagination always follows awakened intelligence. The Egyptians, therefore, could readily imagine what would happen if the Nile floods could be extended beyond the embankments; the parched deserts would be watered and more crops could be grown there to provide the needed food.

How the amount of the crops was increased

What was more natural than that the idea of digging ditches through the higher ground should suggest itself to them? That was exactly what they did and when the next flood came the water poured through the ditches and spread over the deserts beyond. There it remained until the river subsided again, then sank into the ground. Crops were planted and harvested on this newly conquered territory. Thus the Egyptians found a means, through a little extra labor, to double the area of their farm lands.

So far as we know now this was the first time that irrigation was put into practice. Painted pictures and sculptures on old monuments tell us that four thousand years ago the people of Egypt had already begun to dig these irrigation canals. From these first crude ditches developed a wonderful and complicated system of canals, regulated by sluice gates and embankments. The lands, once so parched, they divided into big oblongs separated from one another by low dikes, each oblong being from two thousand to twenty thousand acres in extent. From the canals the water would pour into the first series of oblongs. When the fields there were thoroughly saturated the sluices in the dikes would be opened and the water would pass into the next series of oblongs until finally, when all the land had been well soaked, what was left of the water would be allowed to run back into the river lower down.

Some of the other marvelous engineering works in ancient Egypt

No doubt it was the engineering skill developed by these irrigation works which encouraged the Egyptians to undertake more ambitious feats; the tombs of their kings and the pyramids testify to their abilities. Not satisfied with mere canal digging, one king hollowed out a big reservoir for storing the flood waters, that they might be used during the periods of low water. This was Lake Moeris, which was supposed to be at least 2500 acres in extent.

Though they were perhaps the first, the Egyptians were not the only people of antiquity to practise irrigation. In the valleys of the Tigris and the Euphrates, where Nebuchadnezzar set up his golden image and where today lies the Bagdad of the Arabian Nights, may still be seen the dry beds of canals that were even bigger than those of Egypt. Here were dug two of the largest canals of ancient times; the one drawing water from the eastern bank, the other from the western bank of the Tigris Each supplied many lesser canals which threaded and watered vast stretches of level plain. The big canal on the eastern side was known as the Narhwan. It was 250 miles in length, its depth was from 36 to 50 feet and its average width was 400 feet.

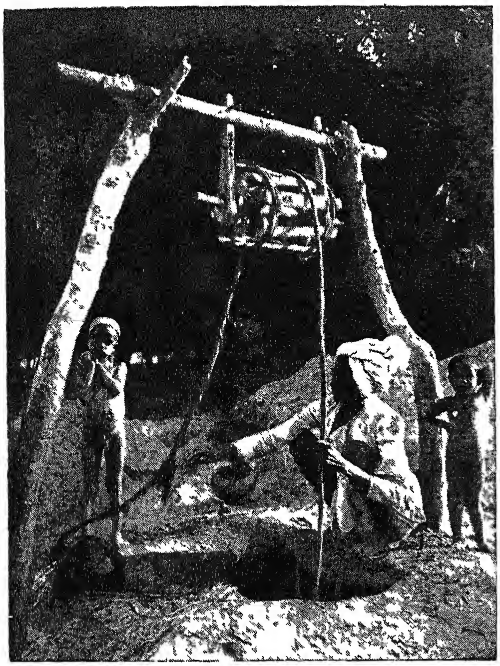
The Hindus also practised irrigation in India long ago before the Christian era

The Hindus, too, were watering their fields artificially long before the beginning of the Christian era. But here entirely different conditions demanded the exercise of their ingenuity. India is not a rainless country, like Egypt and Mesopotamia. On the contrary, it is one of the rainiest countries on the globe. In one province, in Assam, there have been years in which six hundred inches of rain have fallen: fifty feet of water! As twenty inches is considered sufficient for farming without irrigation, we might well suppose that the farmers of Assam had no need to worry.

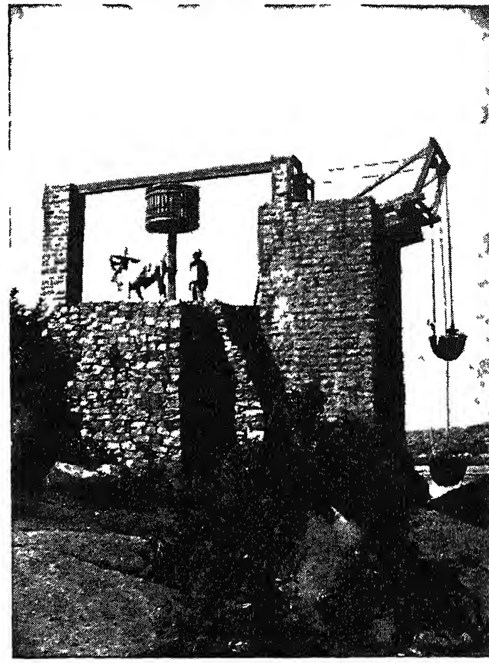
Yet in spite of all this downpour the crops of India frequently wither before they can be harvested. The trouble is that all this rain falls nearly at one time. Sometimes half the rain for the year comes down within two weeks. In some provinces it is not unusual for two feet to fall within forty-eight hours.

Then, of course, the fields are flooded, but after the torrents have washed off into the rivers there is likely to be no more rain for months and the fields become dry and parched. If these dry periods are more than usually prolonged, the crops wither before the harvest and the result is one of those horrible famines from which India has always suffered.

INTERESTING PRIMITIVE IRRIGATION



INDIAN PEASANT IRRIGATING HIS RICE-FIELD



PRIMITIVE WATER-LIFT IN HYDARABAD

BULLOCKS DRIVEN DOWN AN INCLINE TO HAUL UP WATER FOR IRRIGATION

Such were the conditions in the great, fertile valleys of India in ancient times. At uncertain intervals would come the drought years and it was not unusual for half the population of a famine district to die of starvation in the midst of their withered crops, though only a few miles away rolled mighty rivers with water enough to flood the land.

Some of the primitive methods of irrigation used in India

It was the poor farmers themselves who first thought of irrigating their fields. These first rude attempts resembled nothing so much as helping the water climb stairways until it reached a level from which it could flow over the fields along the banks. Steps or terraces were dug out of the embankment beside the river. At each step or terrace was a contrivance the same in principle as we sometimes see employed in the country to draw water from wells: a long pole, see-sawing on the top of an upright pole, with a stone at one end and a bucket suspended from the other. By means of these scoops the water could be raised from the river to one step after another, each of which was provided with a wide hole, to contain the water From one hole to the next above, the water would be lifted and poured, until the man working the top scoop could empty it into a wooden gutter, from which it flowed down into an irrigation ditch. To this day such methods are employed in those remote sections of India not yet reached by the modern canal systems.

The Persian wheel which may be seen to this day

Another early method was the Persian wheel. This resembles an old-fashioned mill-wheel, but where the mill wheel is fitted with paddles the Persian wheel has buckets attached which scoop up the water as the wheel turns, emptying their contents into a wooden flume above. Crude as it is, this method is really very effective and is even used in this country today by small farmers. Sometimes the Persian wheel was turned by oxen, sometimes by the flow of the river, paddles being attached beside the buckets. Thus the power for lifting a steady stream was taken from the river itself and the wheel turned day and night, without human labor. Even after the Hindu engineers had built the big canal systems, quite as big as those of Egypt and more extensive, the Persian wheel continued to be used by the native farmers, even until the present day.

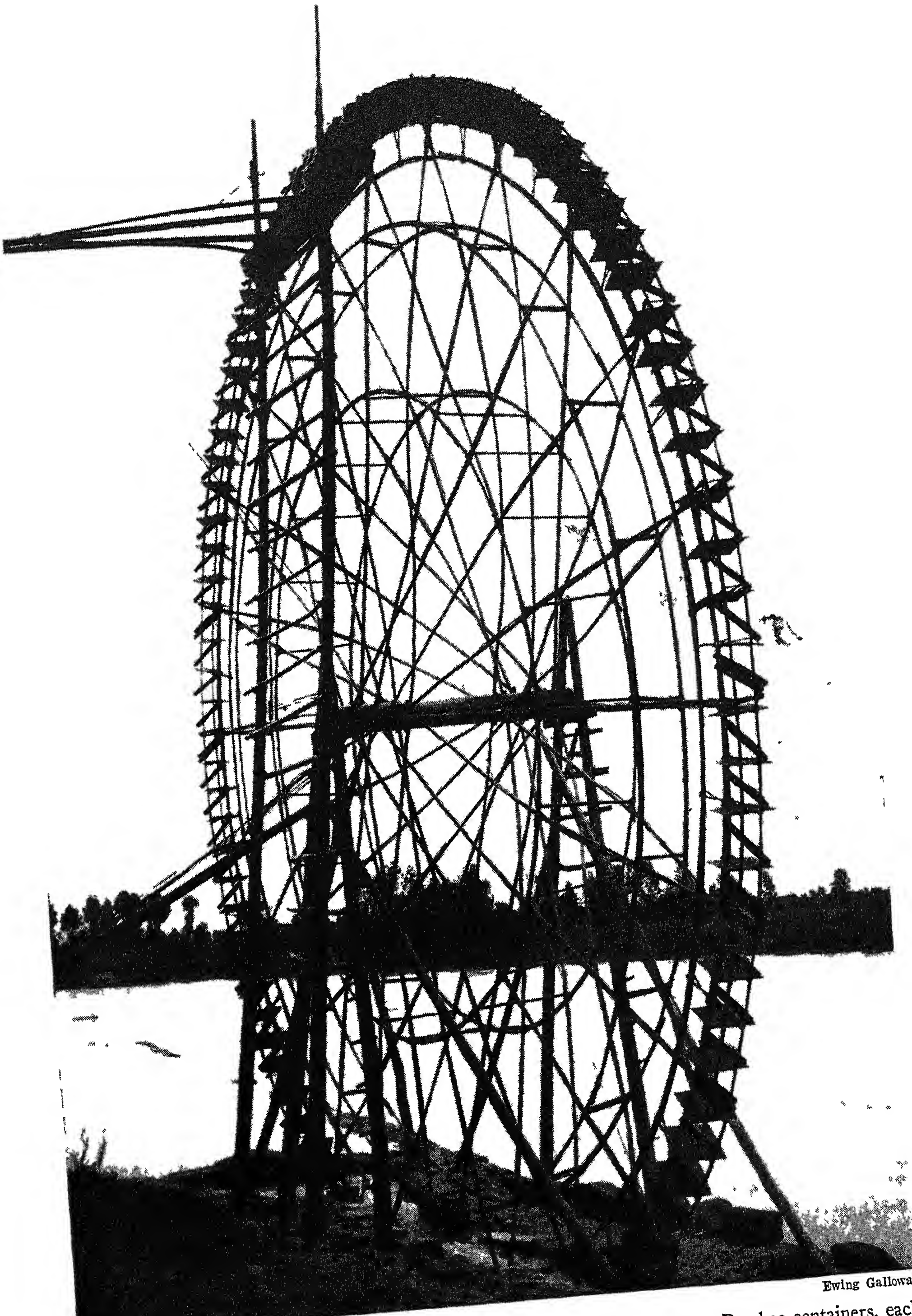
Nearly all of the ancient canals fell into neglect and were filled up by silt, or sediment. The country in the valleys of the Tigris and the Euphrates became practically the desert it is today. The one exception was Egypt. There the old canals were still used by the Egyptians until recent times. It seems only fitting that what is probably the most gigantic irrigation works of modern times should now be found in Egypt.

Modern irrigation works that have created one of the wonders of agriculture

In 1805 Egypt fell under the rule of Mehemet Ali Pasha, who continued in power for over forty years. He was a keenly intelligent man with ideas up to the time in which he lived, though he was of a very nervous temperament. Having the welfare of his country at heart, he determined to improve the irrigating system so that the fields could be watered all the year round instead of only at flood time. This would make it possible to raise valuable crops of cotton and sugar-cane for the European market on the rich soil of the Nile valley.

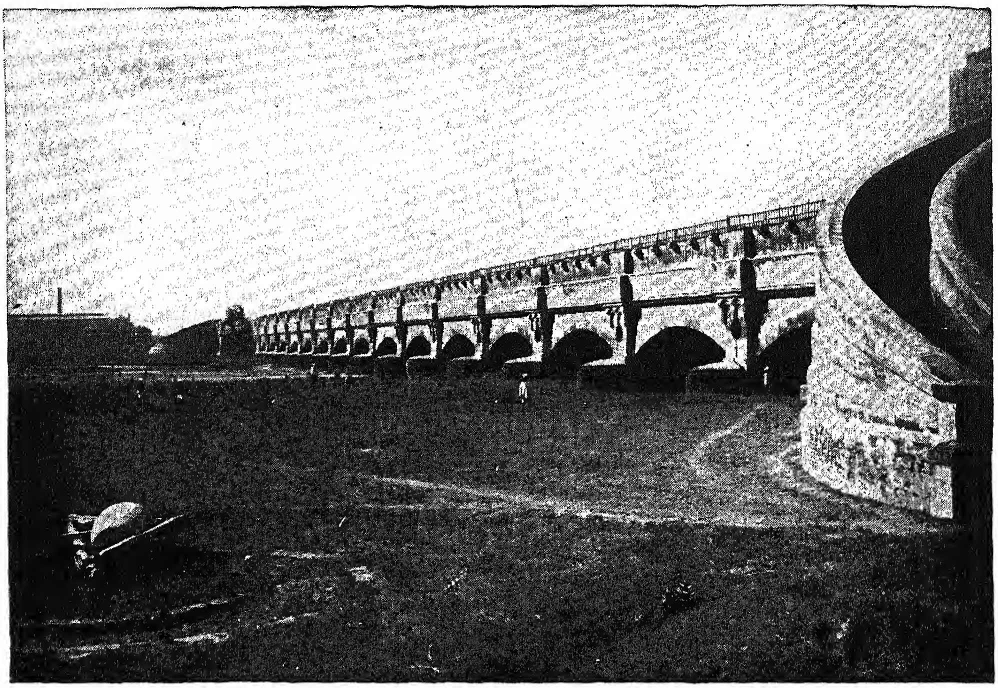
The Nile floods rise about twenty-five feet at Cairo. Mehemet Ali's first scheme was to deepen the old canals twenty-five feet so that the water could flow into them when the river was low. But after a great deal of labor had been wasted it was found that the canals clogged up with silt during the hot months, just when the cotton needed most moisture.

Not discouraged by his first failure, the Pasha next determined to raise the level of the river at low water. This vast undertaking was intrusted to Mougel Bey, a French engineer, and from his plans resulted that great piece of engineering which became known as the Delta Barrage.

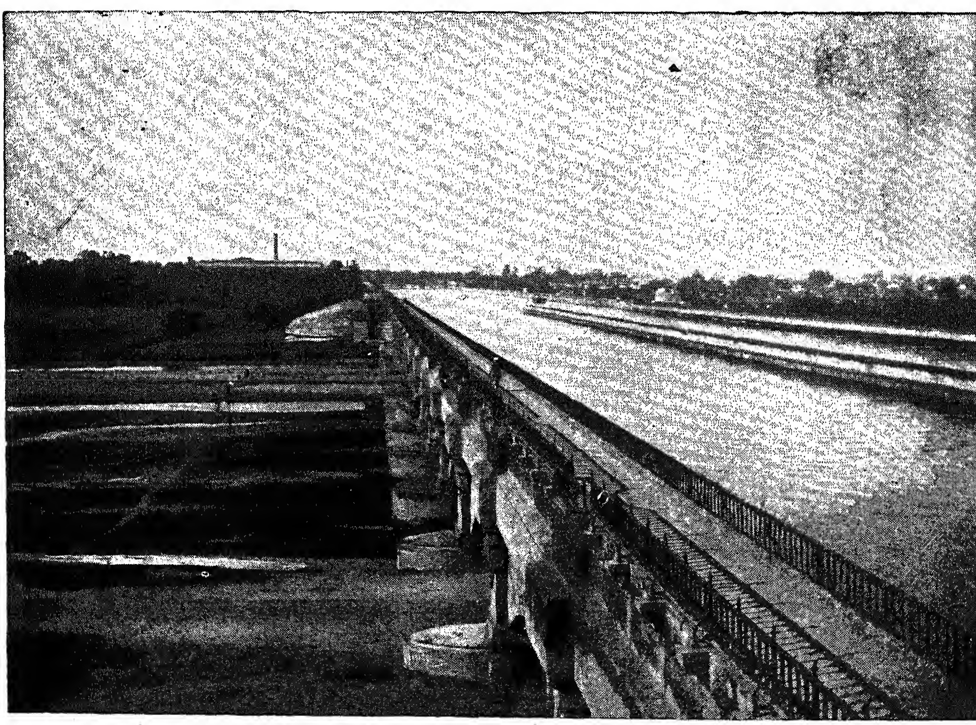


Ewing Galloway

A huge bamboo irrigation water wheel in the Chinese province of Szechwan. Bamboo containers, each holding about a gallon, are filled with water as the big wheel dips them into the stream. The force of the stream turns the wheel and carries the containers to the top. Here they are tilted and spill the water into a trough. Bamboo pipes then carry the water to a flume leading to a rice field.

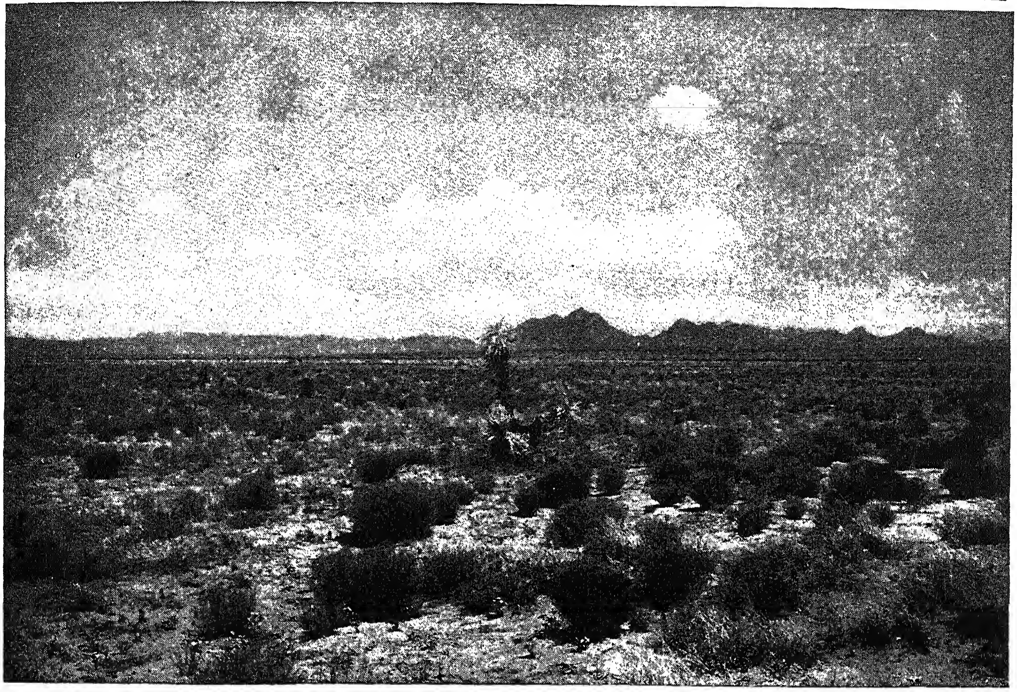


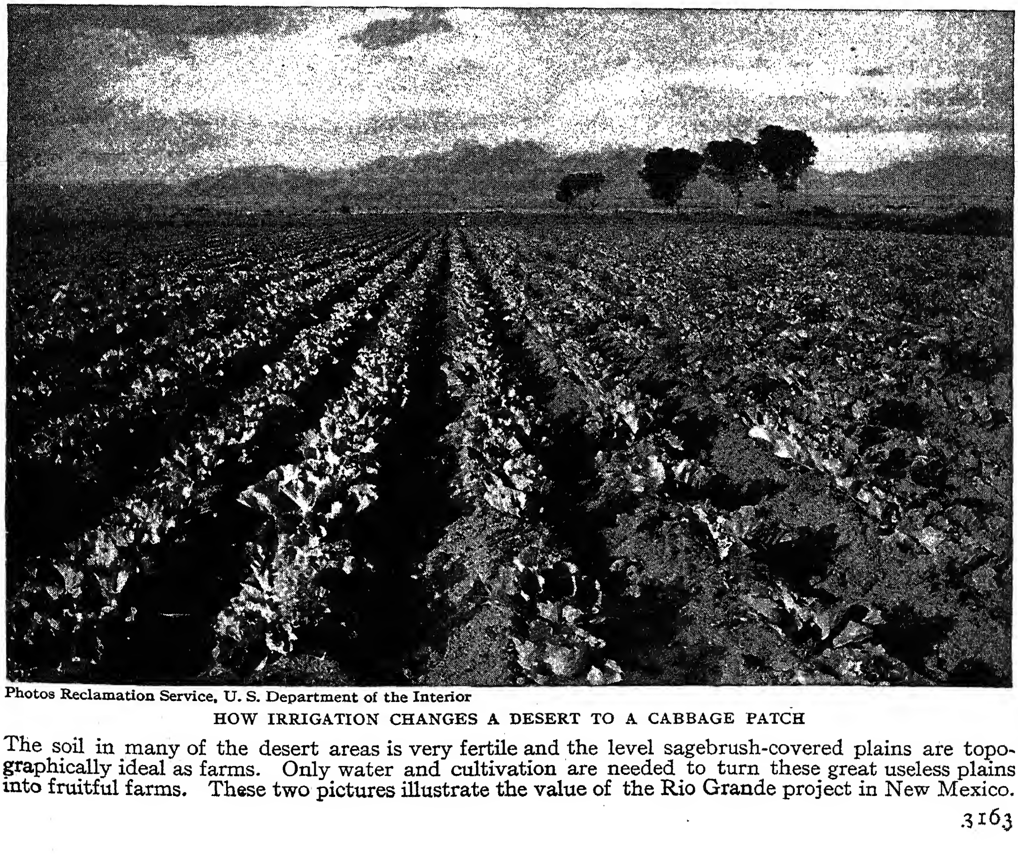
THE SOLANI AQUEDUCT, WHICH CARRIES THE GANGES CANAL OVER THE SOLANI RIVER



THE GREAT SOLANI AQUEDUCT, SIXTY-FIVE YARDS IN WIDTH, AS SEEN FROM ABOVE

MAKING THE DESERT TO BLOOM LIKE A ROSE





Photos Reclamation Service, U. S. Department of the Interior

HOW IRRIGATION CHANGES A DESERT TO A CABBAGE PATCH

The soil in many of the desert areas is very fertile and the level sagebrush-covered plains are topographically ideal as farms. Only water and cultivation are needed to turn these great useless plains into fruitful farms. These two pictures illustrate the value of the Rio Grande project in New Mexico.

The first project of Mehemet Ali failed to stand the tremendous pressure

At a certain point in that part of the valley where the delta begins, the Nile splits and forms two streams, the western being called the Rosetta and the eastern the Damietta branch. Mougel Bey's plan was to dam these two branches just below the split, enough to raise the water fourteen feet. Then he meant to dig three canals: one running down the middle, between the two branches and one to each side. The central canal was finally completed and did good service. The western canal was also finished, but the winds continually blew the sands of the desert into it, filling it up. Year after year it was cleared of sand, but finally it was abandoned as a failure. The third canal was not dug until after the English assumed control.

First of all a concrete floor, 10 feet thick and 112 feet wide, was laid across the two river beds. On this foundation were raised huge, stone piers, spanned overhead by arches, on top of which ran a roadway, or viaduct. Inside the piers, below the arches, heavy gates were fitted, which could be lowered or raised, to regulate the flow of the river. The work was begun in 1843 and lasted twenty years.

In 1863 the gates of the Rosetta branch were raised, but before the waters of the river had risen more than a few feet the flooring sagged and the gates had to be lowered again. Again and again attempts were made to raise the gates, year after year, but finally, four years later, the whole barrage cracked from top to bottom. Then the gates were dropped again for good and the work of Mougel Bey's lifetime was declared a failure.

Naturally these failures were the tragedy of Mehemet Ali's life, while Mougel Bey's skill as an engineer was thoroughly discredited. But others were to use their failure as a stepping-stone to a big success. Today Mougel Bey is held blameless by his profession for the unfortunate result of his great work; the failure of the Delta Barrage is now laid, not to his want of knowledge or skill, but to the nervous temperament of Mehemet Ali.

Haste and temperament the reason for the failure

Against the advice of his engineer Mehemet Ali was continually hurrying the work up. Overcome by his impetuosity, Mougel Bey's workmen laid the concrete foundation in running water. The cement was partly washed away, loosening the rocks and gravel with which it was mixed.

When Egypt was occupied by the British the new government began to consider the necessity of improving the old irrigation system. With this object in view many of the world's greatest engineers were consulted. All agreed that nothing could be done with Mehemet Ali's barrage.

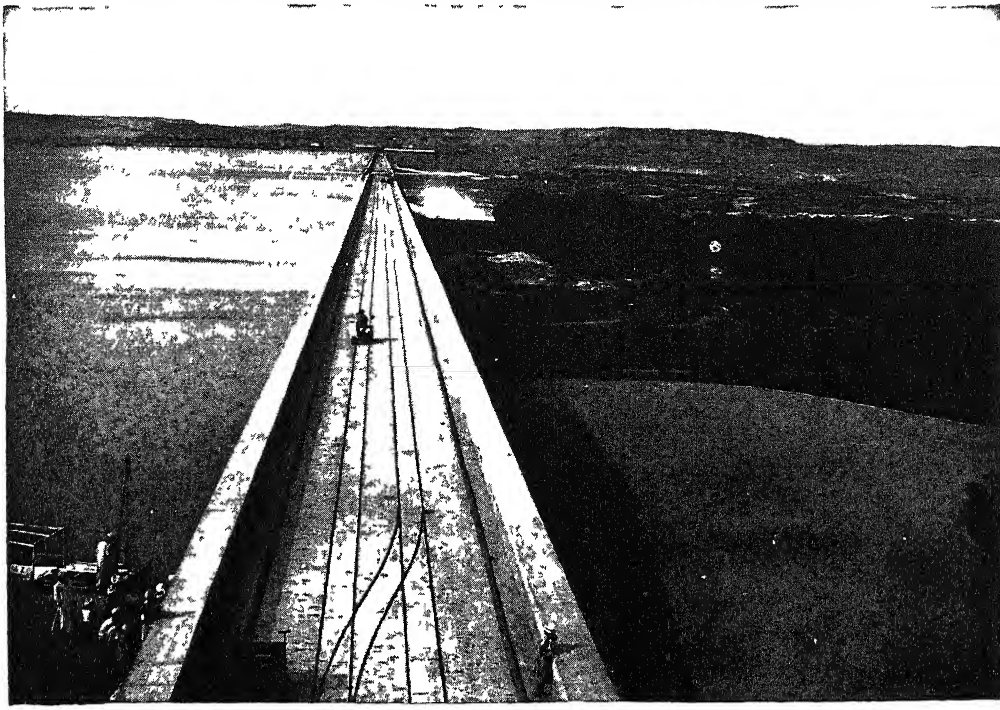
So, in 1883, it was proposed to abandon it altogether as an irrigation work and retain it only as a railroad bridge. A scheme was prepared to irrigate the delta by pumping water from the river.

It was estimated that the pumping plant would cost about three and a half million dollars and the yearly working expense would be another million. But just then there arrived in Egypt an engineer who had been in charge of the canal building in India: Colonel Scott Moncrieff. Into his hands the British government put the business of improving the irrigation works.

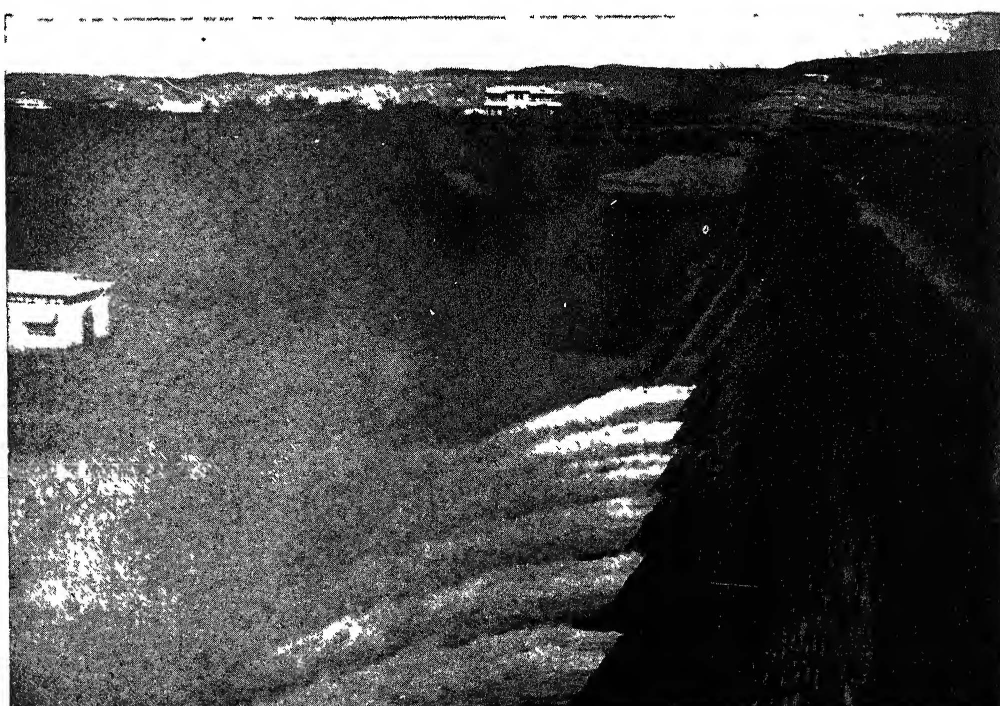
Final success is attained at the delta and along the original lines

The first thing that Colonel Moncrieff did was to veto the pumping scheme. And, to the horror of all the engineering world, he decided to restore Mehemet Ali's barrage. Confident of his own judgment, Colonel Moncrieff began the work.

First of all, he laid another layer of cement on the old flooring, 4 feet deep, and doubled its width. He next bored 5-inch holes from the top of the roadway, down through the piers, a depth of 57 feet, into the bed of the flooring, where the waters had washed out Mougel Bey's cement. Liquid concrete was then poured into the holes, which were 10 feet apart. This concrete, pressed down with great force by its own weight, spread through the washed-out cavities in the foundation, and there became a solid mass.



TOP OF THE ASSUAN DAM FROM EAST BANK OF THE NILE



ASSUAN DAM FROM WEST BANK OF THE NILE

When this work was completed the gates were closed and they stood the strain of the first flood. The barrage was a success. Then the two canals were finished and water began to flow over the delta lands. The result has been a yearly increase of the cotton crops in that region amounting to twenty-five million dollars a year.

Since then the English have improved all the old canals of Egypt and extended their reach. They have also built some great storage reservoirs so that the waters of the Nile can be utilized more extensively during the low flood periods. The biggest of these works is the Assuan Dam built at the head of the First Cataract, 350 miles up the Nile, where the granite bed of the river made an artificial foundation unnecessary.

The height of the dam, as first planned, was 127 feet and it was a mile and a quarter wide. It holds back the Nile waters in a basin extending 140 miles upstream, thus forming the greatest artificial lake in the world. The body of the dam is pierced by 180 sluices, each more than 6 feet wide. These sluices are at different levels and their purpose is to let the first of the floods run through so that the mud will not clog up the reservoir. Later, as the water becomes clearer, the sluices are closed and the reservoir fills. The dam has since been raised another 23 feet.

Much might be told of what the British government has done in India in the way of irrigation works, on a more extended scale even than in Egypt, though none stands out so prominently as the Delta Barrage and the Assuan Dam. Yet by the digging of many canals the famine areas of the past have been much reduced. As an illustration of the influence of irrigation the story of the Bari Doab Canal is of interest. In this section of the Punjab where the rainy season was unusually short and uncertain, the people years ago were wild and warlike, and in the habit of raiding the peaceful farmers of neighboring sections for plunder. But since the digging of the canal they have devoted themselves entirely to farming their lands and have developed into a peaceful, law-abiding community.

Marvels of irrigation in the United States and what they are doing for us

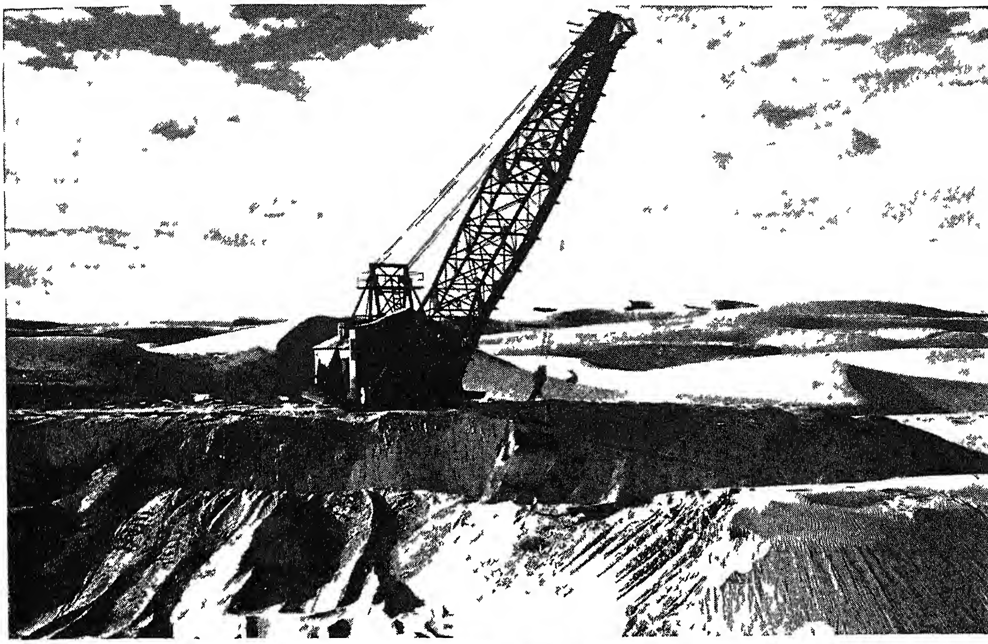
But if irrigation has civilized wild tribes in India, it has accomplished even a greater wonder in the United States. It has raised modern, progressive villages and towns out of the sands of unpeopled deserts. Through its magic influence it has changed the howls of the coyote into the hum of trolley cars and displaced the scrubby sage brush with orchards of fruit trees and fields of waving grain.

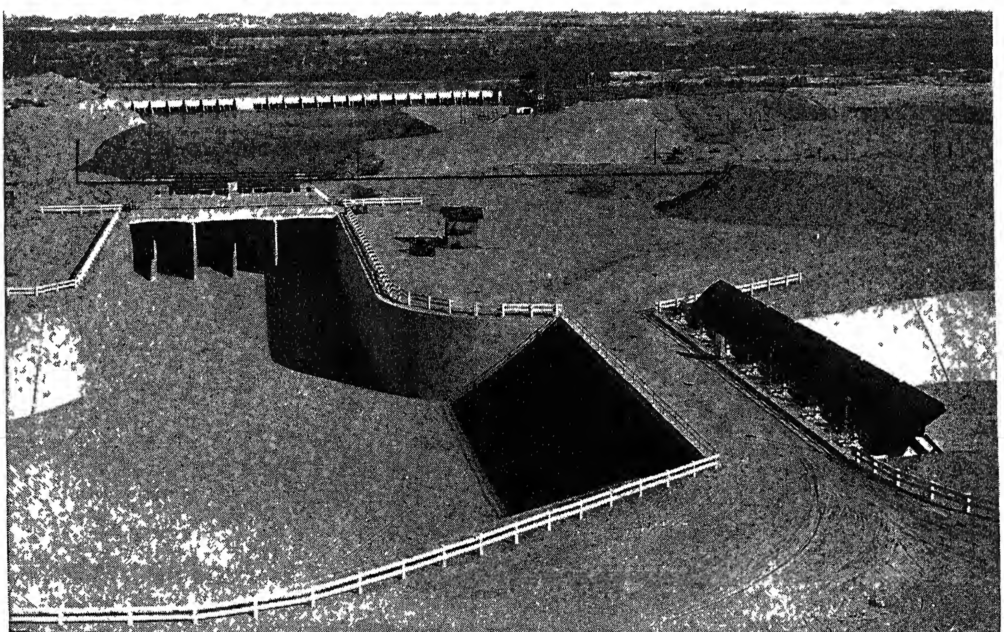
Until quite recently there were vast sections of this country, covering nearly all of the western states, where the climate was too dry for ordinary farming, as practised in the East. The most notable exception was Northern California and parts of Oregon and Washington. Here and in a few other smaller sections more than twenty inches of rain could be depended upon for the cultivation of plant life. All the rest is what is known as the arid, or semi-arid, regions.

These climatic conditions are especially marked in the southern part of the West; in the southern half of California, Nevada, Arizona and New Mexico. Here no ancient people had lived to lay the foundation for an irrigation system, to be utilized and modernized by the people of the present day.

Yet there is one exception. One lonely tribe of Indians had suggested the possibilities of the future. For down in Arizona and New Mexico, where the Pueblo Indians still live, there are to be found the ruins of irrigating canals dug by their ancestors. As indicated by these ruins, it is certain that they built dams and long stretches of canal from which to water their crops. In the Salt River valley, Arizona, there are over 150 miles of old canals. At De Los Muertos, Arizona, there are more of these old water channels, some of them being 7 feet in depth and 30 feet wide. Moreover, it is perfectly evident that they were more than mere ditches, for in parts they are lined with baked clay. Evidently the Indians plastered them with adobe, which they baked by building hot fires over it, transforming it into a sort of brick.

CONSTRUCTION OF THE ALL-AMERICAN CANAL





Photos courtesy Bureau of Reclamation, Department of the Interior

THE ALL-AMERICAN CANAL BRINGS WATER TO THE IMPERIAL VALLEY

The All-American Canal, 80 miles in length, is designed to bring 15,155 cubic feet of water per second from the Colorado River to the thirsty fields of Imperial Valley. Imperial Dam, a 31-foot hollow reinforced concrete structure, was built to divert the Colorado's waters into the Canal. As its name implies, the Canal runs entirely within the United States unlike the former main canal to Imperial Valley which runs for many miles through Mexico. The upper picture indicates some of the difficulties of construction. The drag-line excavator is shown working in the sand dunes east of the Imperial Valley. The lower view is of the Pilot Knob check and wasteway on the Canal, twenty miles below the Imperial diversion dam.

How some of the forty-niners came to seek gold but stayed to farm

The first rush of immigrants from the East went to California, not to farm, but to dig for gold. To supply them with food, enough produce could be raised along the river banks. But as the population increased and the prices of plant foods went up, many turned to agriculture as more profitable than mining. Farms sprang up near the mining communities and the farmers began to consider irrigation.

At first their methods were quite simple. Those living some little distance away from the rivers would combine their labor and dig canals; short at first, then more extensive. In other sections, out of reach of the canals, they dug wells from which the water gushed forth in sufficient quantity to irrigate from a few to hundreds of acres. These were the artesian wells.

Once watered the land proved fertile and rich crops were raised. The population continued increasing. Gradually all the lands situated near enough to water sources for cheap irrigation were taken up, and then the irrigation systems became more extensive and more costly. Companies were formed to undertake these bigger works, and some of their undertakings assumed considerable importance as engineering feats.

The marvelous story of the Imperial Valley

One of these private enterprises stands out prominently; its story deserves to be told in any account of Western irrigation.

In the southeastern corner of California there was a stretch of arid desert surrounded by chains of low, rocky mountains, forming a valley about sixty miles long and thirty wide. Not even the coyotes would venture into this bleak district, though when the Southern Pacific Railroad was built it was found necessary to run the tracks through a part of the valley. One end of it is quite near the Colorado River, at this point about fifty feet above sea level; thence the floor of the valley descends gradually until at its further end it has dropped to a hundred and fifty feet below sea level.

A company of young engineers came that way and an apparently wild idea suggested itself to them. Why not turn part of the river in through the gap and so irrigate the valley? Inspired by the thought, they formed a development company and began to build a dam. They were successful. The water of the river rose behind their dam, then turned through the gap and poured down the valley in a steady stream.

How the Colorado River broke away from man's control

But presently the running water began to excavate a deep bed; it acquired more and more force and volume, and before long almost the full flow of the Colorado was pouring down into the desert valley. Down in the center was a hollow basin which had probably once been an inland sea. This basin began filling, higher and higher, until the bottom of the valley became a vast sea. Higher and higher rose the water; by this time the engineers had lost control of their enterprise.

Then the water began submerging the railroad tracks. They were moved back, but again they were submerged. And now the Southern Pacific began to threaten the engineers. They were to blame. The railroad would sue them. But they had not the capital to build works that would turn the river back to its old bed.

Finally the railroad company acquired control. With its wealth it was able to go to work. A strong dam was built, the flow was checked and the inland sea began to subside. Then the original plan was carried out properly; a canal was dug down the valley and settlers began to flock in to farm.

Today this old desert, now known as the Imperial Valley, is settled by a community of prosperous farmers, growing wealthy on the produce of their farms. Nowhere in America can such cotton grow. Six and eight crops of alfalfa in one year may be harvested on the land watered by the canal; the best dates ripen there as they would in the far Orient. Oranges, lemons and grapefruit are ready for the market weeks before the citrus fruits of other parts of California are ripe.

TREASURES OF THE QUARRY

The Building and Paving Materials Sent into the Cities by the Stone-Workers of the World

STRENGTH FROM EARTH'S CENTRAL FIRES

THE quarrying of stone is, next to agriculture, the most universal of the great industries. Leaving out coal — a form specialized by its composition, uses and the depths at which it is worked — the getting out and shaping stone is a large part of man's work in almost every quarter of the civilized world.

Nearly every country and district has its building stone, although there are lands of sand, gravel, mud and dust where but few are used, and yet a sort of civilization has long existed. It is so, for instance, in the wastes of Yarkand and the ancient cities of Mesopotamia, but in the latter country the sun has almost made brick a natural product.

There are, too, lands where timber supersedes stone for many purposes, as on the great plains of Russia and the prairies of the West. But, allowing for these formidable exceptions, the range of the quarryman is remarkably extensive. Not many countries can be named where all the principal kinds of stone cannot be found, hard or soft, smooth or grained.

Though stone is heavy and unwieldy, it is valuable enough to be carried to and from all parts of a country, according to its qualities in use or beauty. Where are Massachusetts, Vermont and Rhode Island granites not carried? Who does not know the oölitic limestones of Bedford, Indiana, the slates of Vermont, the sandstones of Ohio, the marbles of Vermont, Tennessee and Alabama? And all these stones are repeated in many parts of the United States and other countries of the world. Such stones are not only used in the regions where they are found, but they are exchanged wherever carriage is feasible.

"Where are you sending these stones?" was asked of the owner of a quarry in Derbyshire, England, who was having fine sandstones shaped and dressed by machinery. In reply, the stone merchant took two invoices from his pocket, showing that one of the stones was going to Trondheim, in Norway, and the other to Nova Scotia, — long journeys over land and sea for such heavy and unwieldy cargo, but quite characteristic of the value put on stone suitable for special uses. The use in the case of these machined millstones was the pulping of wood for paper-making. Such an illustration of the removal, for thousands of miles, of the stones of the earth suggests a new view of quarrying.

What wonder if the instinct that led man to make his first weapons of stone has led him, later, to use the stone of his neighborhood, or maybe stone from afar, for his own shelter, security and eventually for his artistic delight?

The chief uses of stone suggest the universality of its working. It is needed for a very wide range of man's activities, beginning early in his civilization and going on late. Building himself a shelter with the loose stones of the rocky wild would be an early advance on seeking refuge from the weather in a cave. In this way the man could choose his place of residence, instead of depending on the chances of the atmosphere and water in making caves. The stone-built house is common to all lands where stone abounds. Indeed, it has been argued, with some degree of truth, that the original style of architecture of each country is dependent on the kind of stone found there.

As civilization advances, stone must meet the competition of other building materials, such as wood and brick and steel. Wood and brick are now generally preferred in the construction of small houses; steel, frequently combined with concrete, is used extensively for large structures, such as skyscrapers and suspension bridges. However, stone is still highly prized as a building material. It is often used for buildings and other structures in whose construction beauty, dignity and endurance are the main considerations. In the case of buildings whose basic material is steel or brick, architects often specify stone for ornamental purposes. They favor this material for facings, halls, floors and pillars, where they wish to obtain particularly pleasing effects.

Stone often serves as a material for artists

Certain kinds of stone are natural materials for art. The leap from the rough, rock-built huts of primitive peoples to the statuary of the Athenian sculptor Phidias, working in Parian marble, is a long one indeed — almost as long as the range of man's intellectual progress. Yet it all lies within the limits of the fascinating story of stone.

The rocks of the earth serve in other ways, too. As we shall see, broken stone is used for the construction of roads and also for railroad ballast. A large amount of crushed limestone is employed for agricultural purposes. Immense quantities of stone, finely broken or ground, go into the manufacture of glass. The quarry, therefore, supplies materials that are used for the home, for industry, for transportation arteries and for art.

How the different rocks are formed

The rocks that are put to these varied uses vary widely in their character and origin. We should have at least some idea of the formation and structure of granite rocks, sandstones, limestones, slates and marbles before we consider how all these materials are used at the present time.

Rocks are divided, geologically, into three main groups. First, there are the rocks that have solidified from a molten mass; these form the igneous group, which includes granite, porphyry and basalt. In certain cases, igneous rocks were broken up into fragments in the course of the ages. Later, these fragments were compacted and cemented to form the rocks of the second group — the sedimentary rocks. Sandstone, mudstone, shale, limestone and dolomite all belong to this group.

The origin of the metamorphic rocks

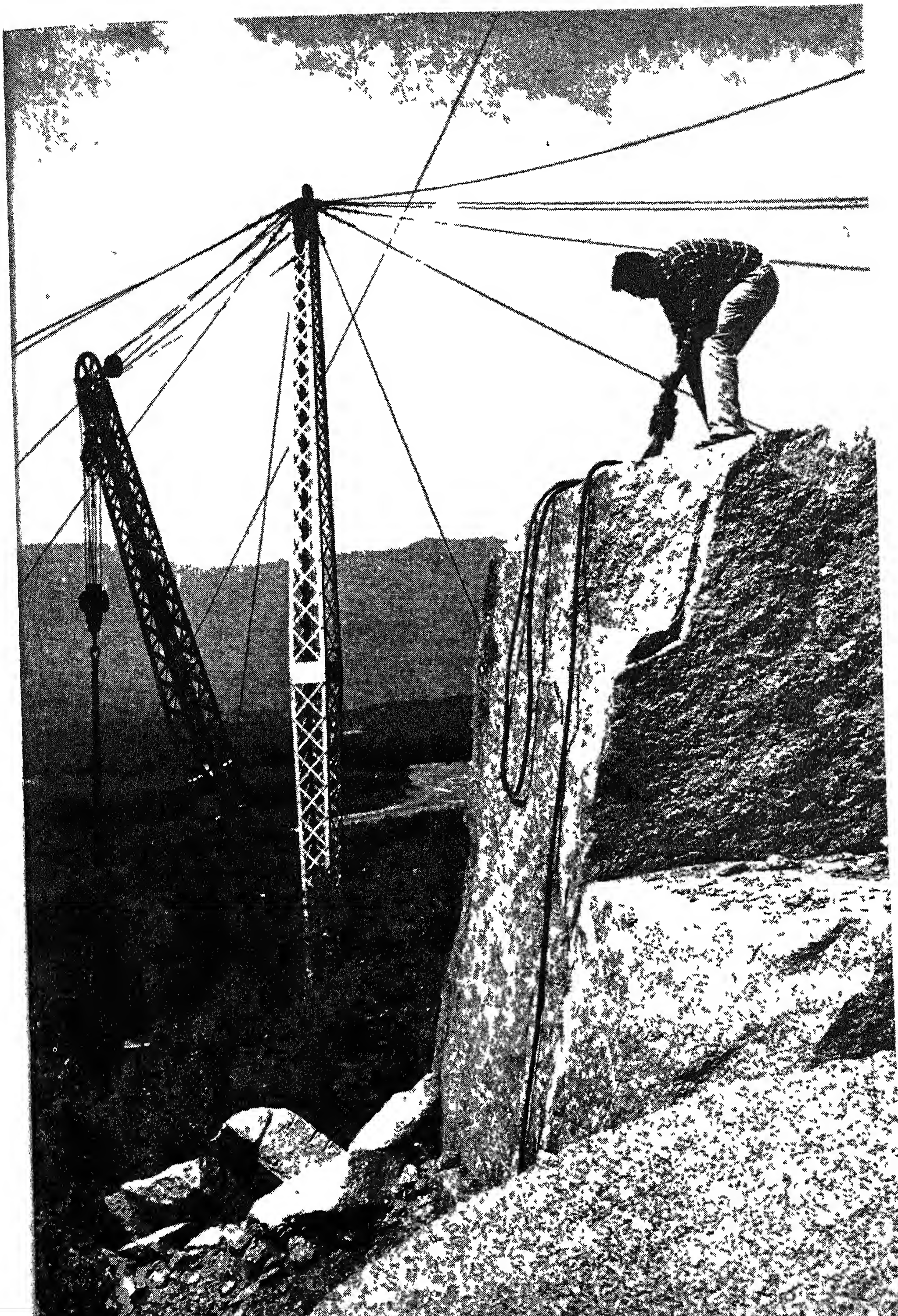
In the third group, we find rocks that were originally igneous or sedimentary and that were later transformed by temperature, pressure and other factors operating within the crust of the earth. The name metamorphic is given to the rocks of this group; they include marble, slate and schist.

There are various kinds of igneous rocks. Those of the so-called plutonic type (of which granite is an example) solidified and slowly cooled deep down under the surface of the earth, where they were subjected to heavy pressure. In the course of time they were often injected through weaker overlying beds. These afterward weathered away until their plutonic core was left bare. In plutonic rocks, crystallization (chiefly into quartz, feldspar and mica) has been complete.

Certain igneous rocks solidified in small masses from the molten state; they cooled more quickly and their crystallization is less distinct Porphyry is a good example of these hypabyssal rocks, as they are called. Finally, there are volcanic rocks, which cooled rapidly at the surface of the earth, as in the case of basalt. In this rock crystallization is imperfect and in some cases, as in the natural glasses, it may be entirely absent. Such forms are called amorphous.

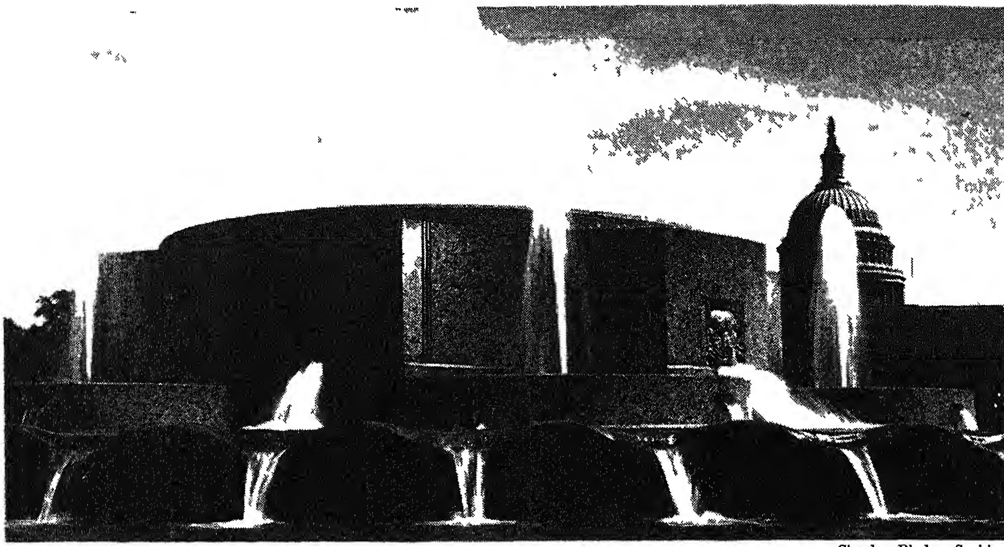
Strength and endurance are associated with igneous rocks

The igneous rocks furnish the stone that is used wherever strength and endurance are required. They are used more extensively than any other kinds of rocks for building purposes; they are crushed for



Black Star

Granite quarry at Redstone, New Hampshire. New Hampshire is famed for its quarries of fine granite.



Charles Phelps Cushing

Beneath this magnificent granite fountain, in Washington, D. C., is a tremendous underground garage.

road making. Though the metamorphic rock known as marble has been the favorite material of artists working in stone, igneous rocks have also served for art work, particularly with modern methods of dressing and shaping by pneumatic power.

Granites are the most widely used of all the igneous rocks. They are made up chiefly of quartz and feldspar, with a certain admixture of mica (a black variety of mica) and, occasionally, of hornblende. They generally occur in the field in great masses, which cover extensive areas; these masses frequently form the cores of mountain ranges. There are a good many different varieties of granite; the distinctions between these types are based on composition, color and texture.

Other igneous rocks are more or less closely allied to the granites. Thus the rocks that are known as the diorites have much the same texture as the granites; they differ from the latter chiefly because they consist mainly of feldspar and contain little or no quartz. A good many of the igneous rocks, other than granite, have what may be called granitic qualities: that is, they are hard, tough and will take a polish. These rocks are quarried and used much as are the granites.

In the United States granites are quarried in the states along the Appalachian Mountains from Maine to Alabama, and also in Minnesota, Wisconsin, Missouri and California. Vermont is the most important producer of granite; the quarries of New Hampshire, California, Massachusetts and Maine are also very valuable.

Of the Vermont stones, the Barre and the so-called Hardwick granites are particularly well known. The former occurs in several shades of gray and is used largely for monumental purposes; it was employed, for example, in the Calhoun Monument in Lexington, Kentucky. Hardwick granites are either gray or white; the white variety was used in the construction of the Wisconsin State Capitol at Madison. The granite in the Pennsylvania State Capitol at Harrisburg came from Woodbury, Vermont.

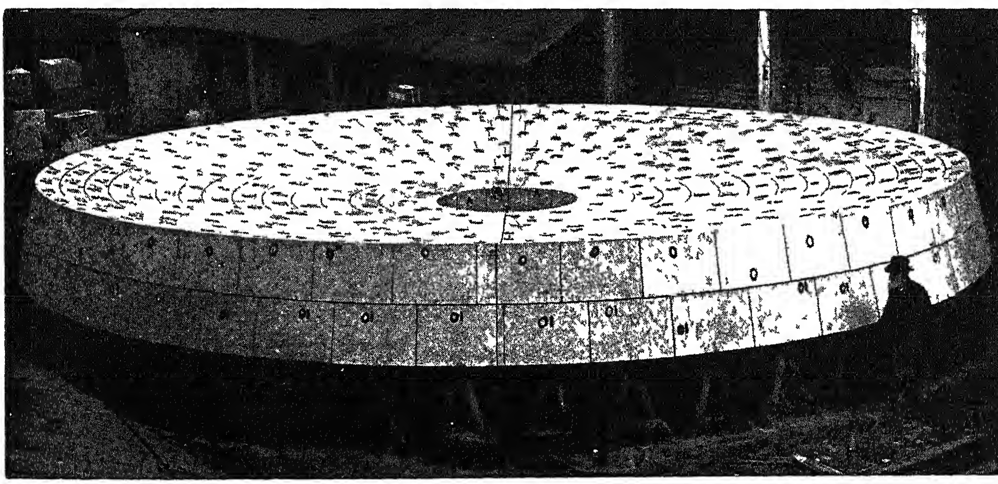
Fine building granite is quarried in many areas of New Hampshire; the popular name of this state is the Granite State. California also contains extensive granite areas; this rock makes up the core of the Sierra Nevadas, besides occurring in smaller scattered districts. It is from light to dark gray in color, and it is put to a wide variety of uses. A number of western states, other than California, produce granite only for local use.

Several well-known granites are quarried in Massachusetts. At Milford there is a pink variety, and the quarries of this town supplied eighty-four 31-foot sectional columns for the Pennsylvania Railroad station in New York City. Gray and green granites come from Rockport, whence they are transported by water to the cities of the Atlantic seaboard. Quincy granite is noted for the high polish it will take, and has found wide use as a monumental and ornamental stone.

With a few exceptions, such as those of Hallowell and North Jay, the Maine granite quarries are located along the seaboard. General Grant's tomb, on Riverside Drive in New York City, was built of "white granite" from North Jay. Several pink granites are quarried on islands along the coast, especially near Rockland. One quarry in this region supplied sixteen columns, each 26 stone feet long and 6 feet in diameter, for the Cathedral of St. John the Divine in New York City. These were to have been 54 feet long, but this proved to be too great a length to stand the strains of the lathe in which they were to be turned, and the columns had to be made in two sections.

Granites from Westerly, R. I., Stony Creek, Conn., Port Deposit, Md., and Mt. Airy, N. C., are well known, as are also the pink and red varieties from Wisconsin, Minnesota and Missouri.

In all countries, however, granite has been one of the most popular of building stones. The red granite of Syene was fashioned by the ancient Egyptians into obelisks, sarcophagi and colossal statues, and employed by them in building their temples, pyramids and palaces. Scotch granites are the coarse red from Peterhead, and the gray from Aberdeen. They are used in the United States for monumental work. Both gray and red granite are quarried in Canada, stone of one or both colors occurring in British Columbia, near Victoria; in Quebec, around the lakes at the heads of the St. Francis and Megantic rivers; in Ontario, near Kingston; in New Brunswick, near St. George; and in Nova Scotia, near Shelburne.



GRANITE BLOCKS FOR THE FOUNDATIONS OF THE VICTORIA MEMORIAL, CALCUTTA, FITTED INTO THEIR RESPECTIVE POSITIONS AND NUMBERED AT THE QUARRY SAWMILL BEFORE SHIPPING

Granite is so tough that it must be blasted to detach it from the mass. Sometimes it is loosened in enormous quantities, by elaborately arranged blasting, so that tens of thousands of tons are at once made available for division into marketable blocks. It is sawed, not by a toothed saw, but by an untoothed steel bar, that cuts or abrades the rock by friction on minute steel filings; the groove, once begun, is filled with water and with hard steel particles, which furnish the cutting surfaces as the bar is moved backward and forward in the gash by machinery. The dressing of granite is now chiefly done by chipping with chisels worked by pneumatic power.

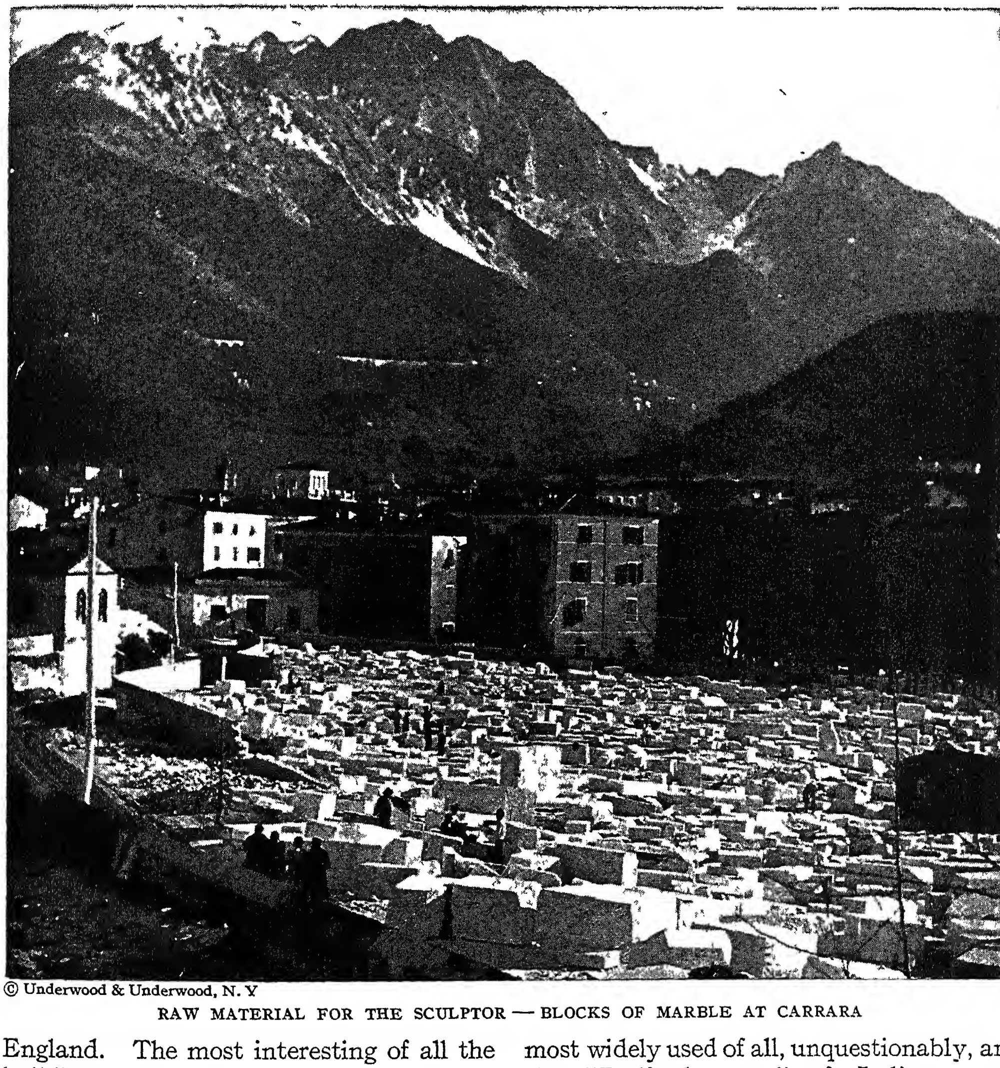
So far, we have only touched the quarrying where strength, durability and a massive dignity are qualities of the stone won, or where the primal fire-welded cohesion of the rock is such that it will break up into lesser and lesser pieces, and still retain its power of resistance, thus making a solid, extremely durable surface for roads, however small the pieces of the rock may be. But now we must turn to the more abundant and more easily worked rocks, that are available for familiar use, and take form under man's hand with less resistance.

Because of the comparative ease in working them, the name of "freestone" is sometimes given to sandstones and limestones, though they are of very different formation, and here must be treated separately. Igneous rocks have been broken up in unnumbered years by weathering, and so carried away, their contents decomposed, and laid down in beds, in which quartz, particularly, remains intact in small particles. The grains, bound together by a strong cement that varies in composition, cover considerable range of sizes, but usually smaller than a pea, and the rock is called "sandstone". Often blocks of the original granite are found bound up with the granular mass, or pebbles and boulders are included. In such cases the rock is called a "conglomerate". Sandstones are quarried in many parts of the country, and make a valuable building stone. They are so widely distributed, and so well known, that it would be difficult to name all the important localities from which they are obtained. The Berea sandstone of Ohio is very much used at the present time; the Medina stone and bluestone of New York are extensively quarried; the red sandstone, or brownstone, of Connecticut and Massachusetts formerly enjoyed great popularity; and the red and brown sandstone quarries of New Jersey are important.

Courtesy The Cleveland Stone Co.

A BEREA SANDSTONE QUARRY AT AMHERST OHIO

Not only are sandstones employed in building, but some of them are used for abrasive purposes as well. Thus the Berea sandstone is made into grindstones, and the Shawangunk grit of eastern New York, into millstones. Pulpstones, for use in paper manufacture, have been imported, for the most part, from Newcastle-upon-Tyne,



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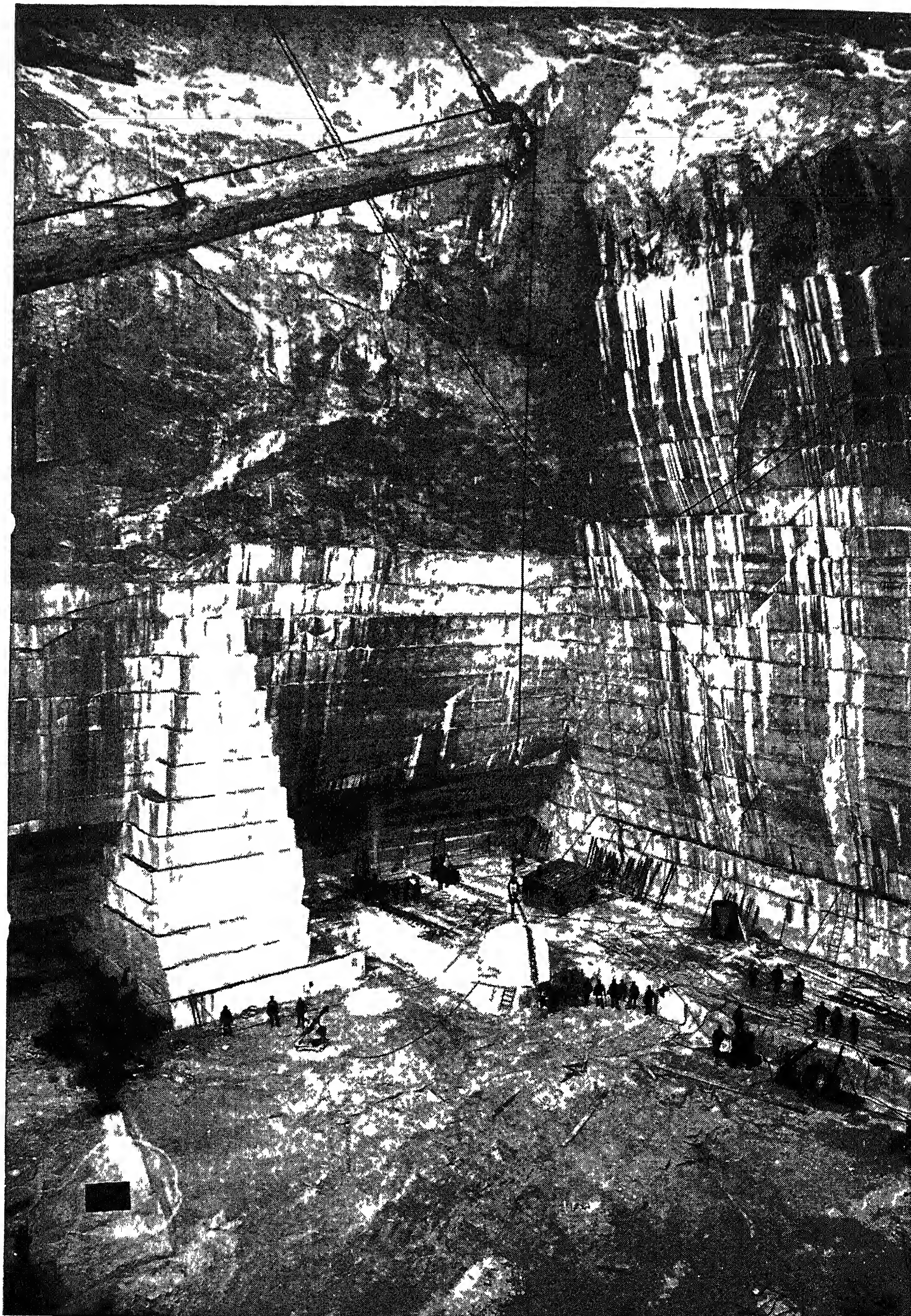
RAW MATERIAL FOR THE SCULPTOR — BLOCKS OF MARBLE AT CARRARA

England. The most interesting of all the building stones, however, are unquestionably the limestones, with their metamorphosed form, the marbles. Limestones have been laid down in the sea, largely by an accumulation of shells and limed skeletons, such as is going on now at the bottom of every ocean. But the depositing of the material is only a first stage; decay, chemical action, crystallization, pressure, have followed, and in the case of marbles the influence in the neighborhood of fire has been felt, causing complete crystallization.

Innumerable limestones with a wide range of color and quality are quarried from many geological formations, but the most widely used of all, unquestionably, are the "Bedford stone" of Indiana and Kentucky, and the limestones of Missouri. Beautiful marbles are quarried in Vermont, Tennessee, Massachusetts and Georgia, but are to be seen in their most effective natural setting in Italy, at Carrara and Massa, inland of the little Mediterranean port of Avenza-Marina.

A QUARRY THAT IS ALMOST A MINE



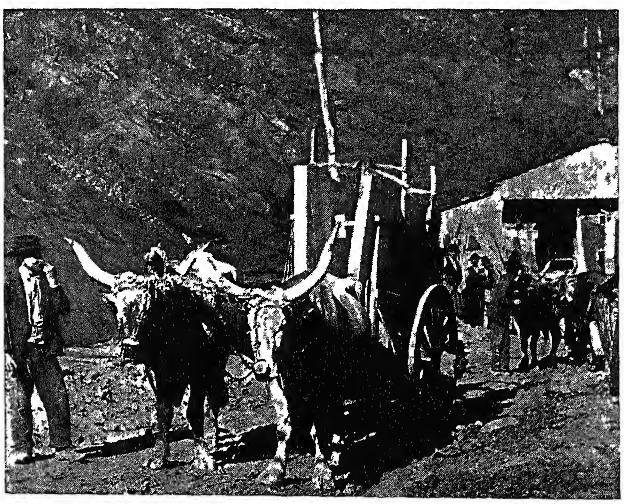
THE FLOOR OF THE VERMONT MARBLE COMPANY'S DEEP QUARRY AT PROCTOR, VERMONT

From *The Titan, the Story of Michelangelo*

A masterpiece in marble — Pieta, by the Florentine painter, sculptor and architect Michelangelo.

While stone-quarrying generally may be regarded as a rough and comparatively simple form of work — though much skill is needed in understanding the bedding and complicated lines of cleavage of such a rock as granite — it assumes a different character when the rock that is to be removed has the fine texture and appearance of Bedford stone or the beauty of marble. The onlooker feels in their presence he is brought into touch with the true materials of art. In this connection the craftsman follows close on the heels of the laborer, and the artist follows the craftsman. It is when the easily manipulated building stones that are also beautiful in structure are reached that we begin to marvel how, from the ruins of the world's oldest crust, the skill of man creates the gorgeous palace and the solemn temple.

The limestone of Bath, England, has been quarried from time immemorial, as shown by the remains of the old Roman baths there, but few who have admired the stone in more recent buildings in other cities are aware that it is quarried not only from the surface but from the interior of the earth, by processes that resemble those of mining. It is generally found between 90 and 120 feet below the surface, and the principal seams are from 12 to 30 feet thick. There are more than 60 miles of underground workings The stone, after being brought to the surface, is left for months to weather and harden. Portland stone, which is of very similar quality, is found at the surface, and is more easily worked in consequence. The features of Bath stone are its regularity of structure which causes it to wear away evenly, its good appearance, and the ease with which it can be worked.



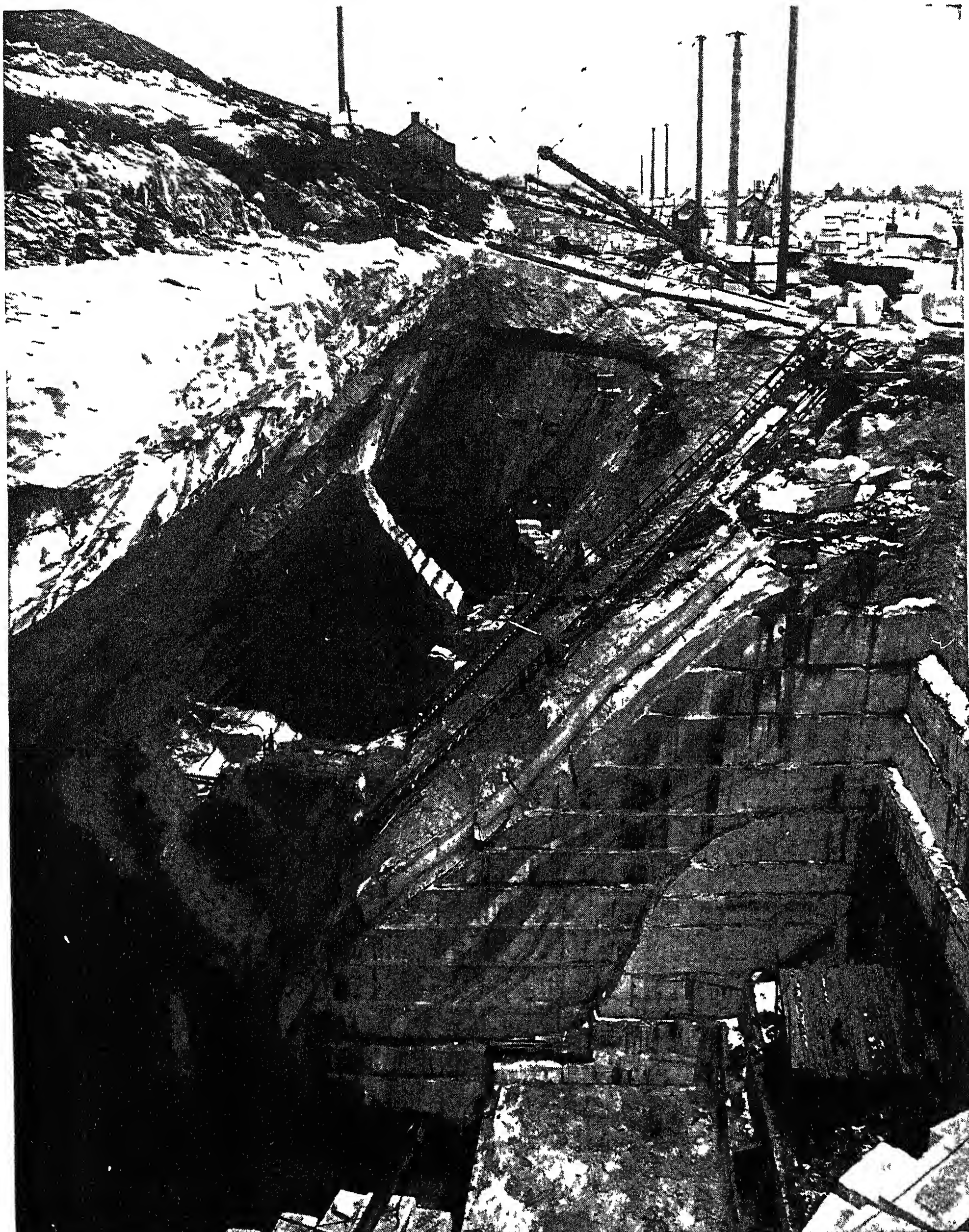
MARBLE SLABS LEAVING CARRARA

How well a rock like limestone can resist heat is a question that might well be asked. It is an important thing to know because of the terrible conflagrations to which our great cities are occasionally subject, but heat alone is not all the stone has to withstand. Streams from the fire hose are poured on to the burning buildings, and the combination of heat and cold water put the rock to a test of remarkable severity At a temperature of about 1600° F. limestone loses the carbon dioxide in its composition and becomes quicklime. When such a temperature is reached in a fire, therefore, limestone rapidly disintegrates, but at lower temperatures it has high resisting power, and withstands the effects of a fire very well. Good sandstone has a somewhat greater fire resistance, that of marble is about the same as limestone, but granite will disintegrate much more readily.

In any case, the power of resistance of a limestone under pressure — its bearing of tons, weight per square inch before being crushed — is not high. Good Indiana stone will withstand five tons per square inch, as against six tons for good sandstone, and twelve tons for average granite. Any good building stone, however, has a crushing strength high enough for all practical purposes. It has been figured that a stone in the base of the Washington monument sustains a maximum crushing pressure of only about three tons per square inch.

Besides the Bedford of Indiana, the Missouri limestones are of importance. The principal one is a strong, light gray, crystalline rock from Jasper County, known as the "Carthage limestone". It is used in the Carnegie Library in Joplin, Missouri, and in the public library in

Kansas City. It takes a good polish and has been used lately in interior decoration. Minnesota limestones are usually yellow



Courtesy Vermont Marble Co

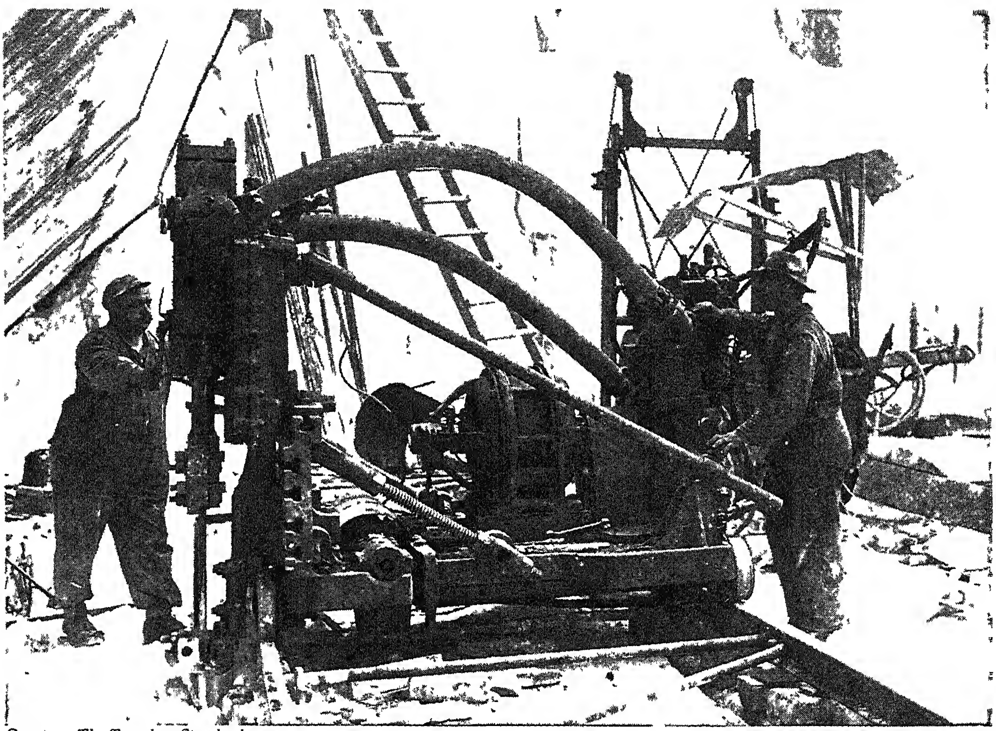
WORKING A THIN BUT VALUABLE LAYER

or yellowish brown, of fine grain, and have an excellent reputation. The best ones are quarried near Mankato and Kasota, in the south-central portion of the state.

Marble, the purest form of limestone and the most beautiful of all rock structures, is a limestone that has been acted on by fire, through the presence in its neighborhood of the molten matter that forms igneous rock. The effect has been to render the limestone crystalline, with a beautiful, fine,

granular appearance. The classical Parian marble and the marble of Carrara are white, but there are lovely colored marbles — blood-red, green, yellow and black. Some of these, exquisite in color and texture, are found in Connemara.

The principle upon which the quarrying of granite is based is that of splitting, because the rock is so hard that it cannot be cut except at prohibitive expense. The quarryman works it where he finds that it will split easily in three directions at right angles to each other, and then with wedges, or a little explosive, he breaks the dimension blocks free. Marble, however, can be cut with steel, and in this country wedging and blasting have given way to the use of machines that cut the rock. These "channeling-machines", as they are called, cut grooves either vertically or horizontally, and deep enough to surround almost any size of block that may be required. Sometimes, also, marble is quarried underground, as, for instance, at Rutland, Vermont, where a valuable layer slopes at a very steep angle, until a depth of about 200 feet is reached, where it flattens out. The working of this layer becomes, therefore, a matter of underground quarrying, which is possible because of the value of the stone.

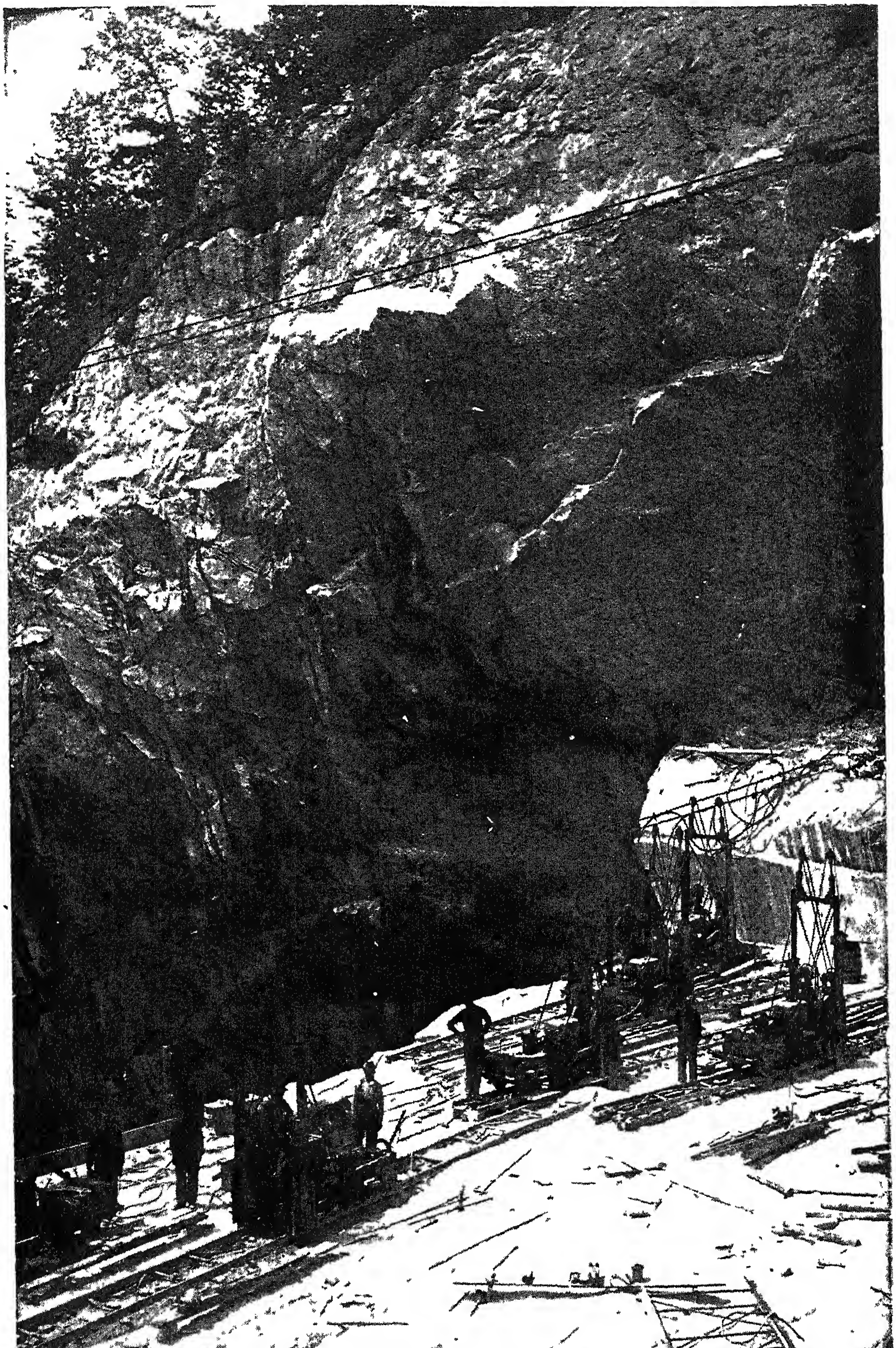


Courtesy *The Travelers Standard*

ELECTRICALLY OPERATED CHANNELING-MACHINE
For cutting long grooves in the rock to facilitate quarrying.

Marble is used in this country — apart from statuary — to a large extent for decoration, for pillars, staircases, interiors, but in Italy, the land of marble, it is gloriously employed in whole buildings, as indeed it was in Greece. The Parthenon at Athens is built of marble from Mount Pentelicus. It was no vain boast of Augustus that he found Rome brick and left it marble — a transformation made possible by the comparative nearness of the Tuscan quarries of Carrara, quarries that from time immemorial have been available because of their proximity to the sea, the great shortener of distances.

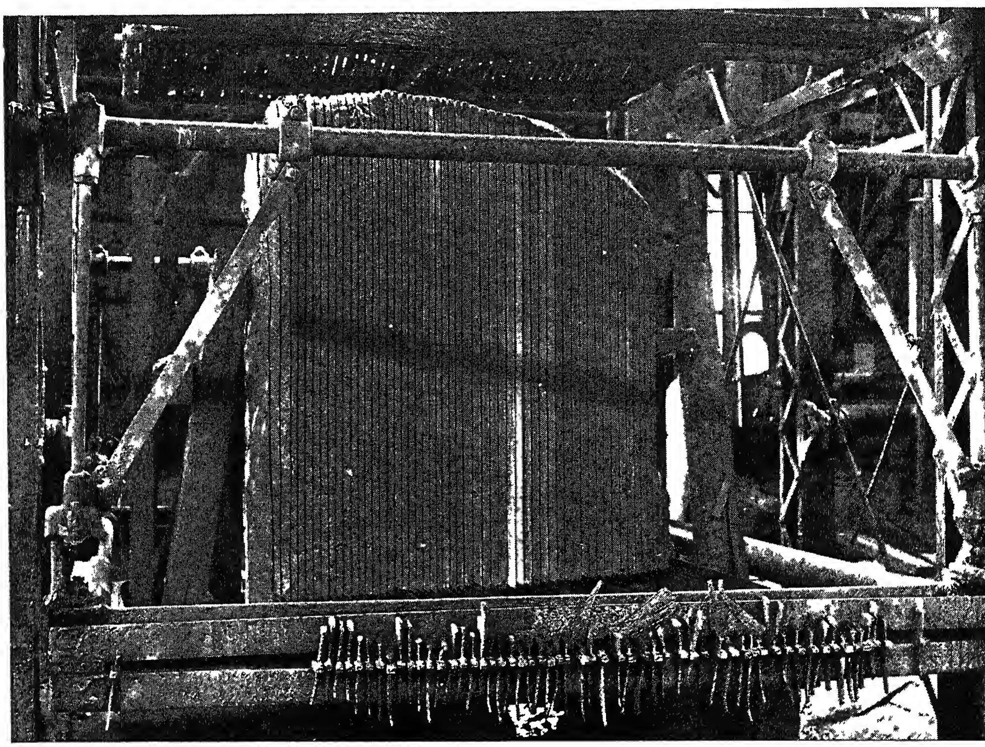
The whole region around Carrara lives on marble today perhaps more than ever before. Travelers to Rome, somewhat short of half-way between Spezia and Pisa,



Courtesy *The Travelers Standard*

OPEN QUARRY SHOWING A NUMBER OF CHANNELING-MACHINES AT WORK

along the fringe of the blue Italian sea, note that the mountains which have long been jaggedly cutting the eastern sky have become scarred with yellowy patches, almost from base to summit. These are the four hundred quarries of Carrara and Massa; and when Avenza is reached the train is beset by brown-skinned Italians who would fain load the passengers with tile-like slabs of beautifully polished marble. Here a little to the right is the tiny port of Marina, to which the from its solid bed in the hills, and roughly squares the blocks; another set lets it carefully down the steep, rocky slope of the hills, on wooden sledges, steadying the sledges with ropes passed round posts by the side of the rough track; and then, at the bottom of the slope, the blocks are loaded by a third set on to ox-trucks, powerfully braked, and so are slowly taken, with much abuse of the imperturbable oxen, to the railroad and the sea, ten or a dozen miles away from the upper quarries.



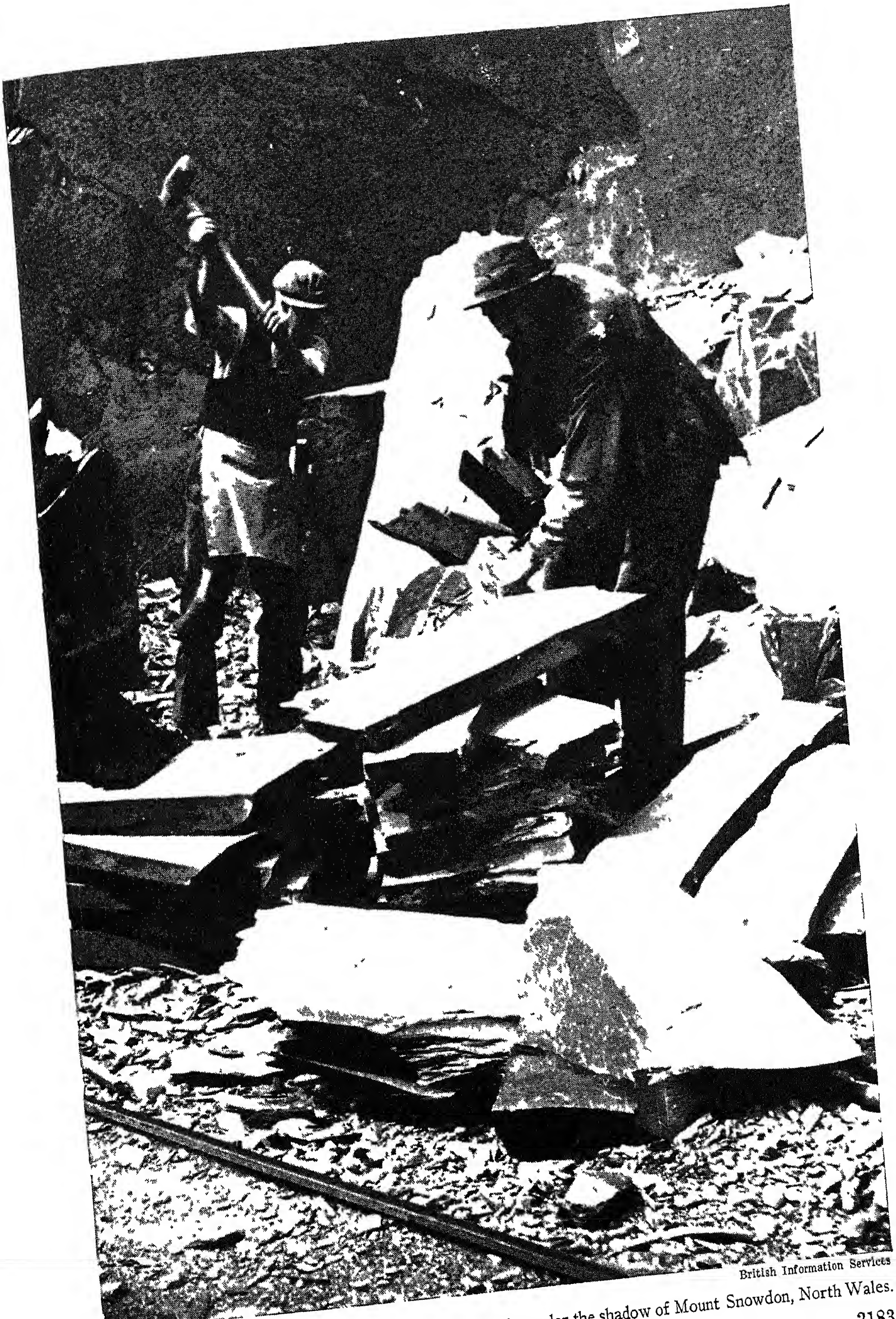
Courtesy *The Travelers Standard*

GANG SAW FOR SAWING MARBLE BLOCKS INTO SLABS

products of the distant quarries on the hills are sent down, for conveyance to all the world. In one way or another seven thousand men are working in these quarries or conveying their spoils to the lazy railway and lazier sea. Considerably more than two and a half million dollars' worth of the beautiful creamy stone is brought down here yearly, a value much increased before its destinations in other lands are reached.

The marble industry of Carrara is a rather elaborate example of division of labor. One set of men gets the marble

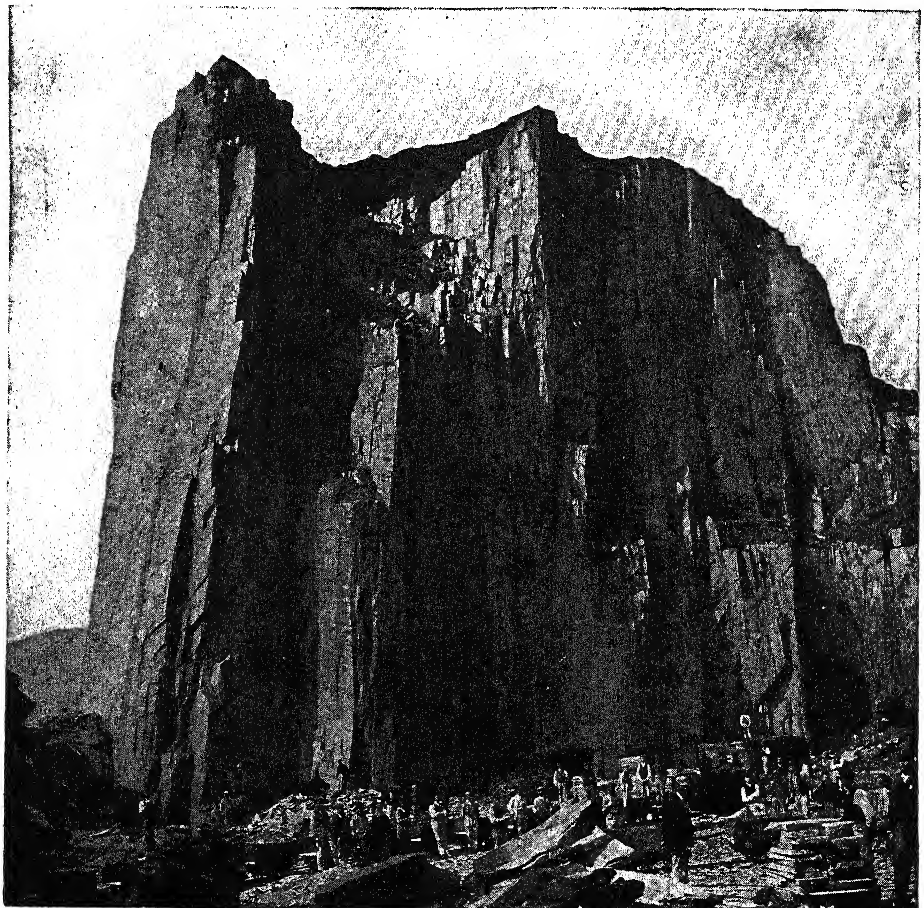
The marble is quarried by blasting with dynamite, a high degree of skill having been reached in so arranging the shots as not to break up the stone unnecessarily. The marble so procured is the raw material for a perfect hive of more or less artistic workers in the towns below. Practically all great sculpture from the time of Michelangelo has been chiseled from stone brought down from these inexhaustible quarries. It is only by seeing quarries like those of Carrara that one can realize how cathedrals like Milan could be built.



British Information Services

Workmen trimming slate in the huge slate quarries under the shadow of Mount Snowdon, North Wales.

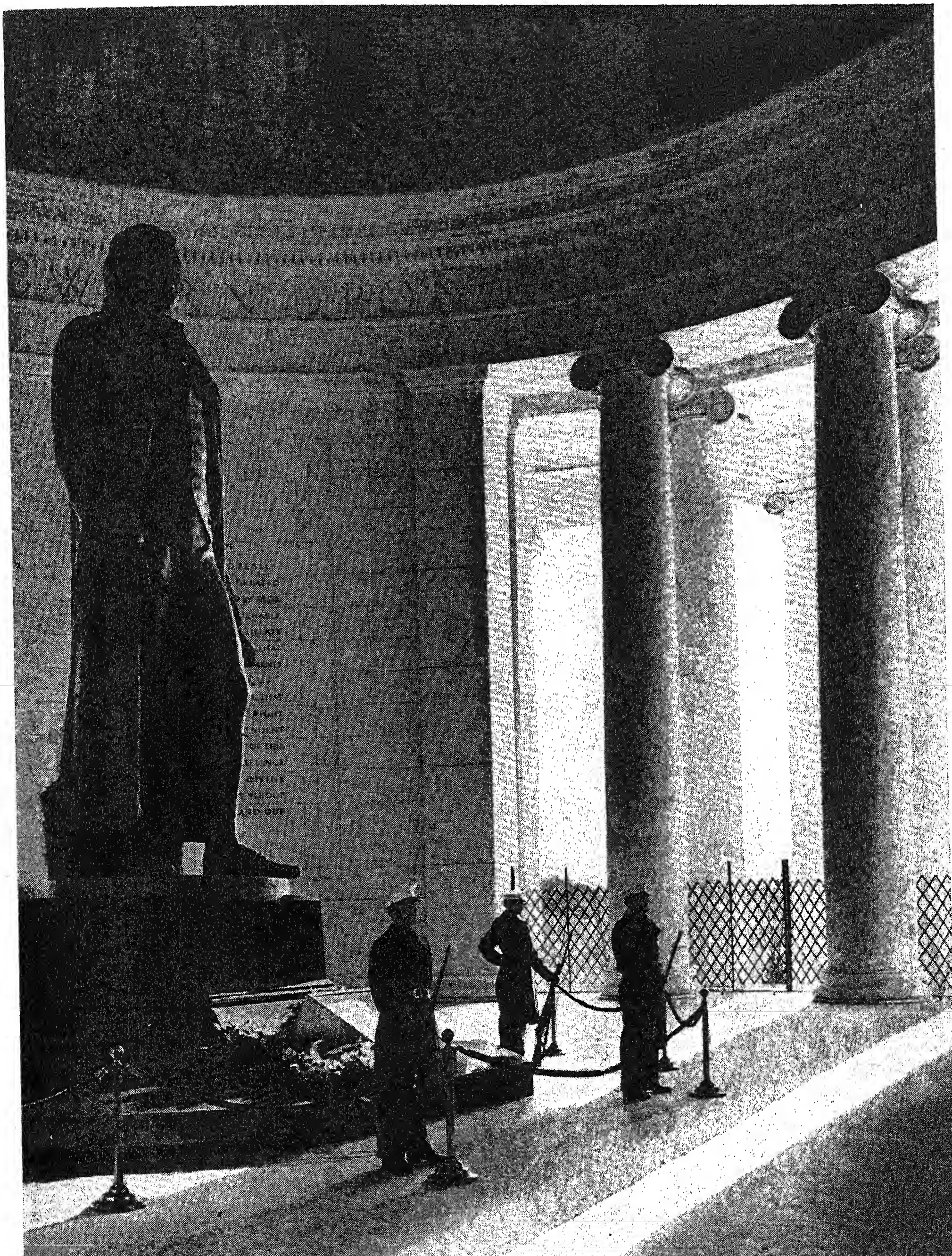
One of the most important, though not the most widespread, forms of quarrying is the getting of slates for roofing and for school use. Slate is a rock that has been metamorphosed or changed by compression. and by stresses on the earth's crust, and both sedimentary and igneous rocks are affected. The special quality of slate that gives it its usefulness is its ready cleavage combined with hardness. The thin, sheet-like character of this material is in no way artificial, but is simply due to the presence of a wonderful grain. The slate as it comes out of the quarry is in the form of a slab, perhaps several inches thick, and irregular in outline. It is passed over to a workman, who drives a thin wedge into the edge of it, and a sheet of roofing slate splits off, requiring only to be trimmed, and holes punched in it, before it is ready to be put to its use. Most of the slates of the United States come from the Eastern States, the quarrying districts forming a broken belt extending from Maine to Georgia. Vermont supplies green and purple slates, and Pennsylvania a dark bluish gray variety. On the border of Maryland and Pennsylvania lies the Peach Bottom slate area.



A MASS OF SLATE 250 FEET HIGH AND ESTIMATED TO WEIGH 25,000 TONS

This glance over a scattered but enormous industry has disclosed to us how man seeks strength for his architecture from the oldest formations that have been nearest the earth's central fires but attains greater adaptability for things of beauty when he is manipulating the rocks which have been re-formed, perhaps again and again by the earth's later changes.

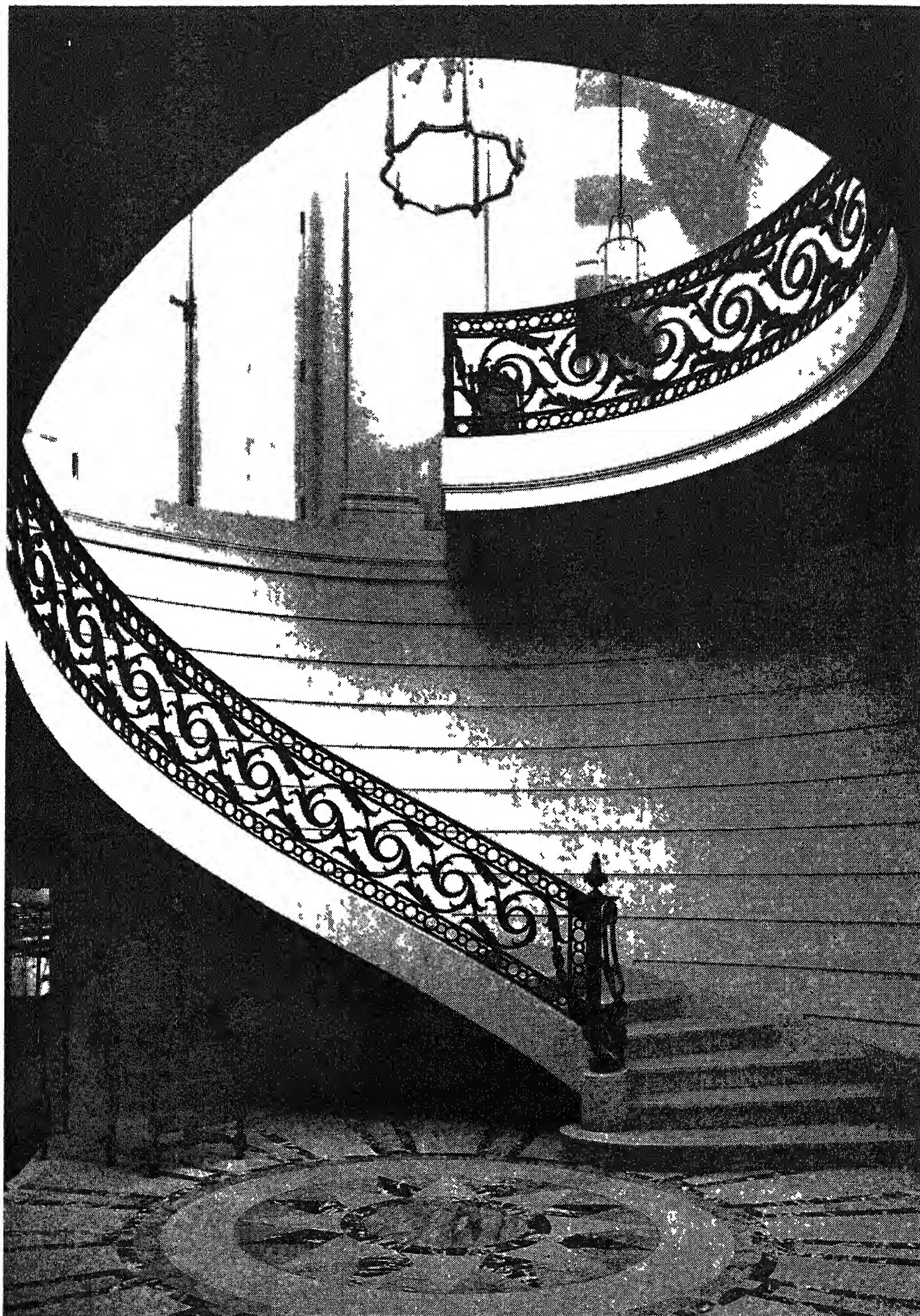
A MASTERPIECE IN MARBLE



Gottscho-Schleisner

The Thomas Jefferson Memorial in Washington, D. C. The dome and the Ionic columns of the beautiful structure are of Imperial Danby marble, from Vermont—white, with a faint brownish clouding.

HOW MARBLE BLENDS WITH IRON



National Academy Galleries

A winding staircase at the National Academy Galleries in New York. Note how the ironwork of the staircase blends with the marble of the stairs and the beautiful mosaic pattern, in marble, of the floor.

SOME ENEMIES OF PLANT LIFE

Parasitic fungi, bacteria, slime-molds, algæ and flowering plants

DISEASES WHICH THESE ORGANISMS CAUSE

IN the present chapter we propose to discuss in a general way those organisms which occur upon plants as parasites, and which cause disease, manifested in various ways. It does not lie within our province to treat of insects and the injury which many of these do to plants, nor to discuss the various types of depredations made on plant life by higher animals and man. We must, moreover, refrain from enumerating or describing the injuries which plants in nature suffer from the ravages of fire, wind, hail, lightning, excessive heat and cold and other physical agents.

Foremost among the organisms which cause disease in plants must be named the fungi. To this group belong the molds that form on fruit and bread, the mushrooms, toadstools and puffballs which occur in lawns, meadows and woods; the shelving or bracket fungi which are often found on decaying trees or stumps; the mildews, rusts and smuts which attack vegetables, cereals and fruits; the bird's-nest fungi; the stink-horn fungi; the earth-stars; and many other interesting forms.

Although many fungi are parasites, causing disease in plants or more rarely in animals, there are many others which live a wholly saprophytic existence and have never been known to cause disease. Saprophytic fungi occur on the ground or on decaying logs or other refuse material. They obtain their nutriment from the dead and disorganized remains of other plants or animals, and when found in the soil use the humus for their food. Parasitic fungi obtain their food from the plant or animal upon which they normally occur, and this parasitized organism is called "the host". None of the fungi are able to live a wholly independent existence. This is due to the fact that they lack the green coloring matter, chlorophyll, which enables all the higher plants in the presence of sunlight to elaborate their own complex food materials from the carbon dioxide of the air and water. Fungi can, in fact, grow luxuriantly in the total absence of sunlight and carbon dioxide. Mushrooms are grown for the market in total darkness in old abandoned coal mines, caves and cellars.

Fungi are of many kinds. We are particularly interested in the parasitic forms but in order that we may better understand these it will prove advantageous to select a common saprophyte for preliminary discussion. We will use for this purpose the very common bread mold, *Rhizopus nigricans*. This fungus occurs throughout the whole world and is a familiar sight to housekeepers everywhere. It grows easily at ordinary temperatures, and occurs particularly on substances of a starchy or sugary nature, such as damp bread, paste, preserved fruit and rotting potatoes. The moldy growth, which in many cases is so profuse that a cottony mat results, is made up of an enormous number of extremely fine threads or filaments which branch repeatedly and ramify the substratum in every direction. If examined with a magnifying glass of even a very low power these threads may be plainly seen, and the whole mat resembles a tangled skein of white twine. These threads constitute the vegetative portion of the fungus and are termed mycelium. The branches which penetrate the food substance obtain the nutriment for the whole fungus body.

How the spores of the fungus bread mold are widely disseminated

Shooting upward into the air from the mass of mycelium may be seen a number of vertical threads, the sporangiophores. Each of these at its apex is swollen out into a globose head called the "sporangium". These sporangia to the unaided eye appear as minute black or brown dots. The sporangium is a hollow sac which bears within a very large number of exceedingly minute rounded bodies called "spores". These spores are analogous to the seeds of higher plants, and are blown by the wind for long distances. They serve to disseminate the fungus, and are able to survive great extremes of heat and cold and will remain alive for a long time in very dry places, such as the dust of the city street. When they fall upon damp bread or some other favorable substance they germinate by sending out a little cylindrical thread called a germ-tube. This grows rapidly in length and branches and soon the white mat of mycelium is developed. The mycelium again develops sporangia and spores, and the life cycle of the fungus is completed. It will be seen that the fungus is of a very simple type.

So cosmopolitan is this fungus in its distribution and so common are its spores in nature that all kinds of starchy and sugary foodstuffs and fruits must be protected in one way or another from contamination by it. For this reason oranges, grapefruit, lemons and apples are commonly wrapped in tissue paper when packed for the market; and since this and other common molds are not able to enter and damage these fruits until after they have been bruised or otherwise injured there is the additional incentive also for careful handling. Fruit which is in any manner bruised permits the entrance of the spores of *Rhizopus nigricans* and other common and equally destructive molds. After the entrance of the germ-tube from the spore, the mycelium develops rapidly and a condition of rottenness is produced. Strawberries which have been picked for the market are particularly susceptible to attack by the bread mold; sweet potatoes also suffer greatly from it.

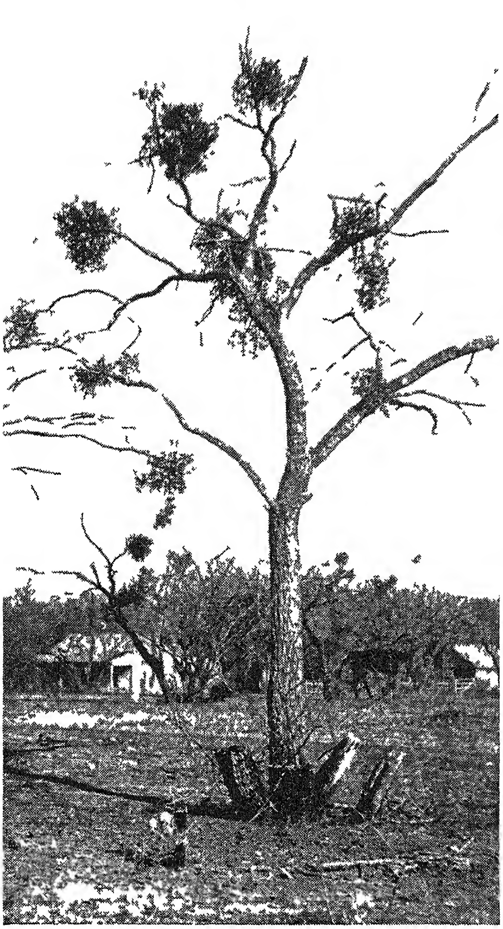
A very simple experiment and one which can be carried out in any home will convince the reader that these molds are everywhere. If a piece of bread be first soaked in water, and then placed in some receptacle where it will remain undisturbed it will be evident in a very few days that it already contained or had come in contact with spores of probably more than one species of mold. Moldy growths will appear over its surface and the small black dots demonstrating the presence of sporangia of *Rhizopus nigricans* will be prominent. If blue-green spots develop these are due to the presence of another mold, *Penicillium*, from which the new and potent medicinal drug, penicillin, is extracted. A single microscopic spore will on germination produce a colony or mat of fungous mycelium of considerable extent in a few days.

Why one often sees mold on the surface of canned fruit even carefully put up

If canned fruit is not sealed while hot, fungous spores may fall on its surface and a moldy growth result. In fact since certain fungous spores are very resistant to the killing action of heat the ordinary methods of sterilization used in the average kitchen often fail to rid the fruit of all the spores. This fact explains the development of mold on the surface of fruit in cans which have been carefully handled. Some fungous spores and certain bacteria in the spore condition will resist a temperature as high as that of boiling water. Fruit or vegetables sterilized with "live" steam (under pressure) in an autoclave will, however, be rid of all viable spores, and moldy growths will not develop.

This brief survey of the life-history and activities of the common bread mold will enable us to understand more clearly the nature of those fungi which cause disease in plants. Before fungi had been carefully studied by botanists, agriculturists in general believed that the rusts on cereals, mildews on fruits, and other similar fungi were manifestations of a diseased condition inherent in the plant. They did not even dream that these evidences of disease were actually microorganisms, and the cause rather than the effect of the malady.

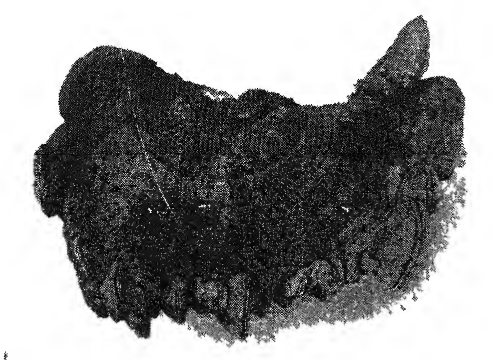
PLANT PARASITES AND DISEASES



U S Forest Service

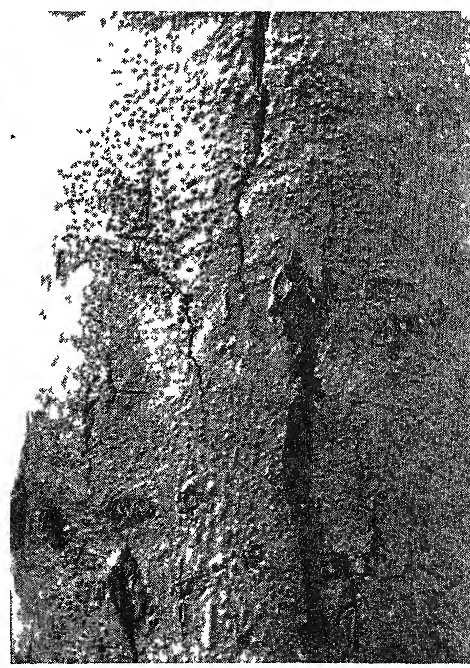
Mistletoe growing on a mesquite tree in Texas The mistletoe, an evergreen parasite, is found on many different kinds of trees, including the apple, the thorn, the poplar, the maple and the locust

Nutgalls on an oak tree. Nutgalls, or galls, are the swellings that develop when small wasp-like insects lay their eggs in the tissues of twigs or leaves. Nutgalls are valuable as a source of tannin, used in converting animal hide into leather.

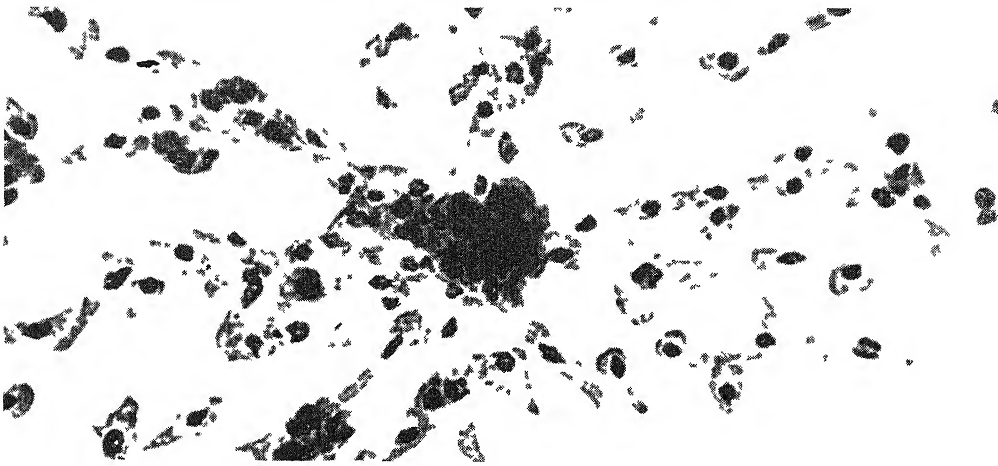


American Museum of Natural History

Bracket or shell fungi. They grow on trees in the form of semi-circular brackets or sea shells.

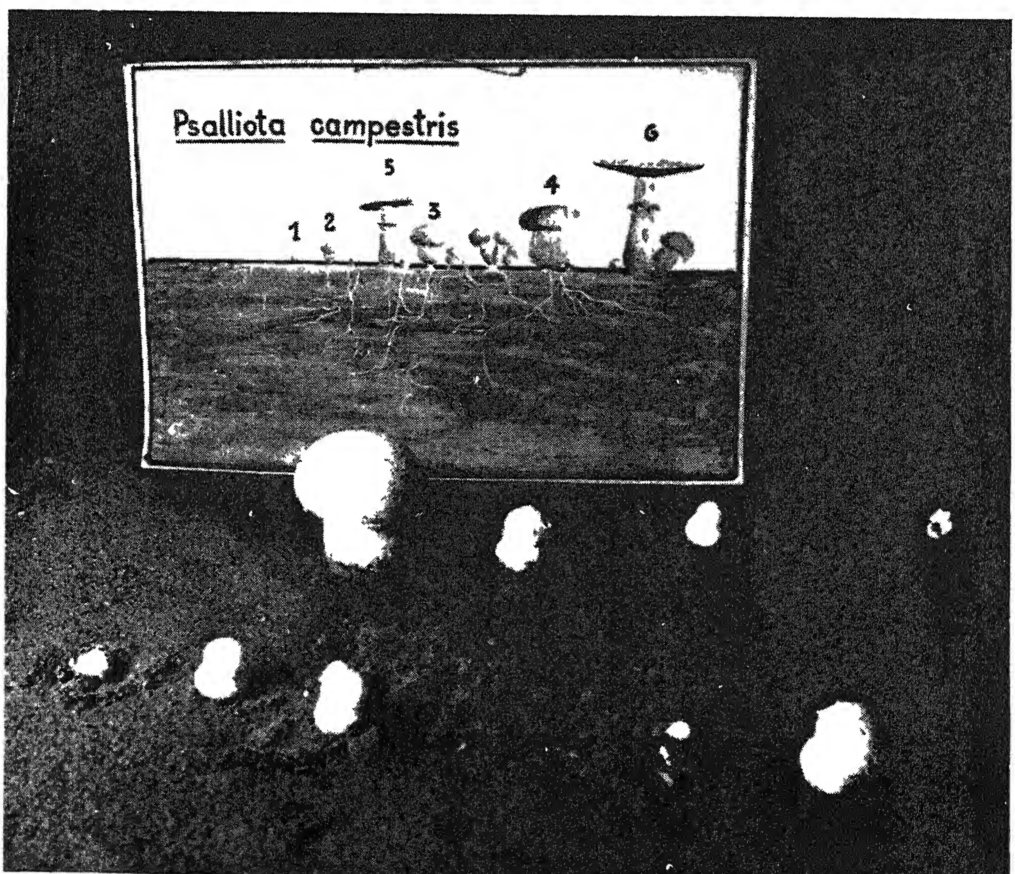


Chestnut tree trunk, showing the ravages of a fungus that has made the tree extinct in many areas.



J T Bonner

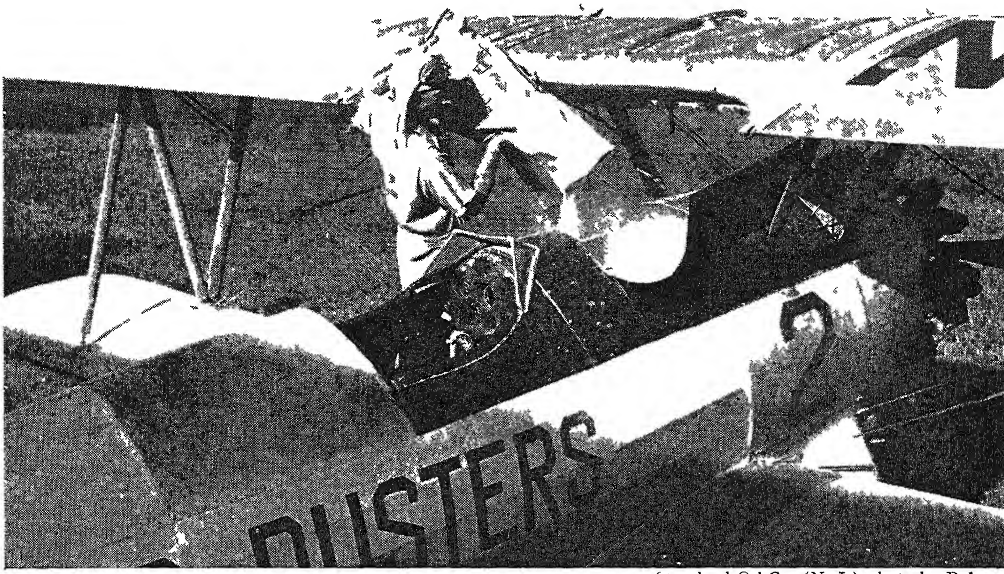
The amazing slime mold (Dictyostelium) The cells of this mold may live as separate individuals that resemble the common one-celled ameba Sometimes, however, a few cells will climb together and then many others—tens of thousands in some cases—will glide over and add themselves to the pile



Black Star

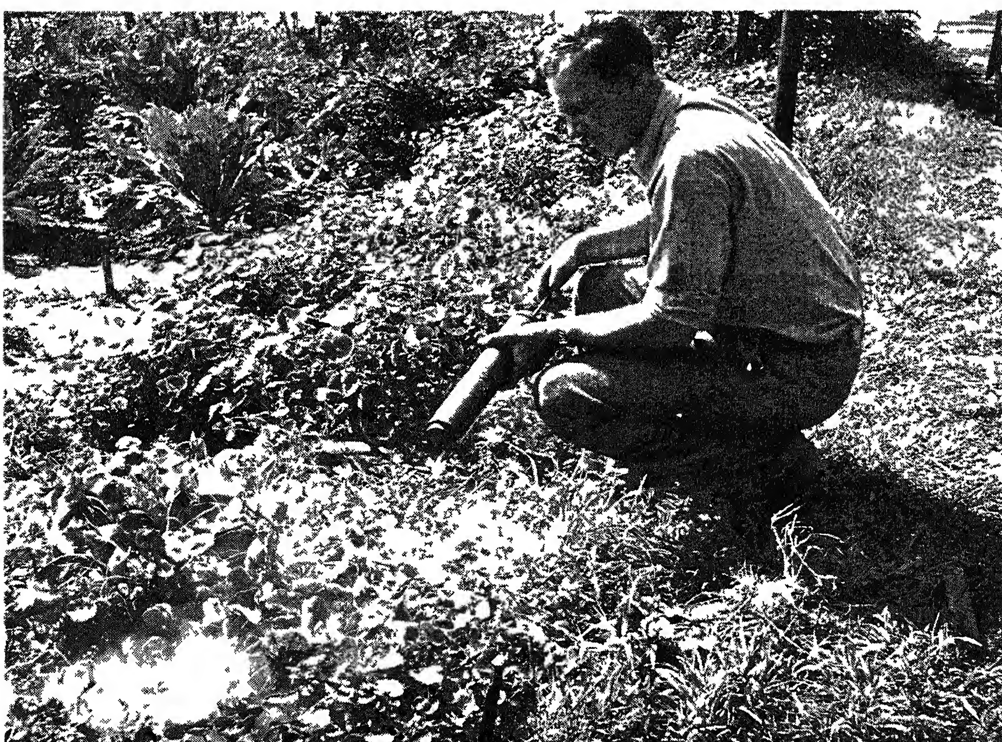
Different stages in the development of a mushroom (Psalliota campestris) Figure 1 shows the growth of the plant at the end of the first day, Figure 2 the growth at the end of the second day and so on.

FIGHTING SOME ENEMIES OF PLANT LIFE



Standard Oil Co (N J) photo by Roberts

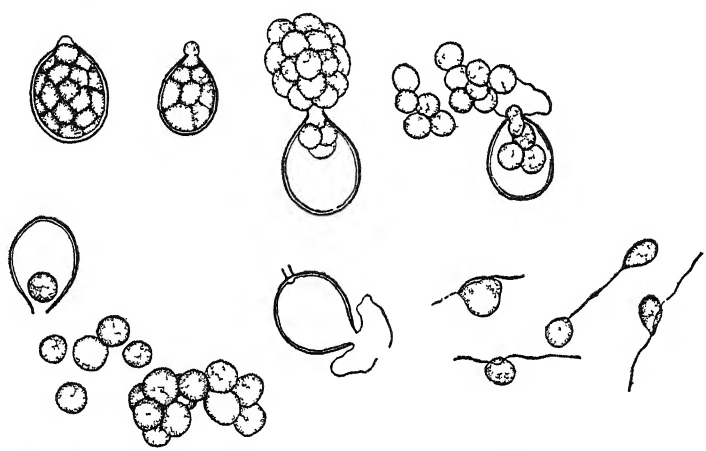
Filling a plane with weevil-killing benzene hexachloride, which will be dusted over cotton fields on a Mississippi plantation The airplane has proved valuable in the fight against insect pests



Standard Oil Co (N J) photo by Brooks

Dusting a nasturtium bed to determine the effect of an insecticide on aphids (plant lice) Aphids do a great deal of damage to vegetation because they suck the sap of leaves and of plant stems

Since then a vast amount of work has been done on the study of fungi. There are thousands of species in this group, no two are exactly alike, and hundreds of them are parasites. The various diseases on the host plants are due to different organisms, only a single fungus being concerned in a given disease. Thus rose mildew is caused by one fungus, grape mildew by another and potato mildew by still another. The differences in the fungi concerned are evident not only in differences in morphology (form and structure) but also from the fact that any parasitic fungus, if placed upon a host plant other than its own, will refuse to infect it. Some fungi do, however, attack several different hosts. The hosts in such cases are usually closely related; for example, several species of rose are attacked by one mildew. Some parasitic fungi which resemble each other so closely in their morphology that they cannot be separated on structural characters have wholly different host plants. Such forms are termed biologic species. There are other fungi which under ordinary conditions live as saprophytes, that in the presence of certain favorable environmental factors assume the parasitic mode of life and attack living plants. These are called "facultative parasites". Others normally parasites may become saprophytes in certain cases. Many fungi which are called parasites live for only a portion of their life-cycle on the living tissue of the host, and complete their existence, often undergoing considerable growth, as saprophytes. Relatively few are obligate parasites, forced to pass their entire life in the host, refusing to develop in artificial culture media.



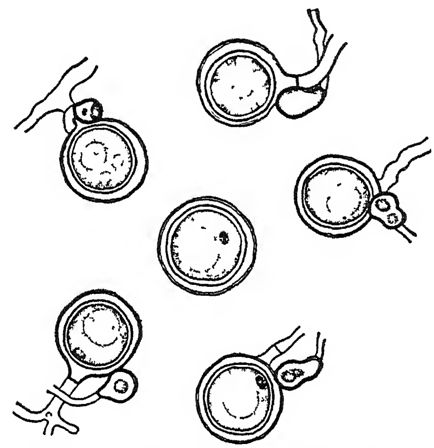
The conidia of *Phytophthora infestans*, cause of "late blight" of potato, germinating to form ciliated zoospores which later come to rest, loose their cilia, round up, put out a germ tube, and infect the host. (After Rosenbaum)

We will now select for discussion several of the more interesting plant diseases caused by fungi, and will call attention to the important differences in the fungi concerned. The condition known as "damping off" in seedlings and young plants may well be chosen to illustrate the nature of diseases caused under certain environmental conditions by facultative parasites. Although several fungi under favorable conditions will cause the phenomenon of damping off the organism usually concerned is *Pythium debaryanum*. Every gardener, amateur or professional, has, at some time or other, had the disappointing experience of finding a large number of seedlings in the seed-bed beginning to wither and die in patches soon after their appearance above ground. This takes place especially when the seed-bed has been placed in a dark or shaded spot and given too liberal a supply of water. Damping off occurs frequently in growing mustard and cress, where the plants usually stand closely crowded. The first symptom of disease is the tendency of some of the plants to bend over at a sharp angle and shrivel up. A close examination reveals the fact that this collapse of the plant is due to the rotting of one side of the stem near the surface of the ground. After the disease has obtained a foothold in a crowded seed-bed it spreads with great rapidity from a central point in all directions, and if allowed to run its course will gradually kill off all the seedlings. If the soil of such an infested seed-bed is used again for growing seedlings the second crop will be infected, and so on for any number of successive crops. It is evident that the causal organism remains in the soil for a long time.

To examine this organism select a diseased plant, section it through the diseased spot on the stem and place the tissue under a compound microscope. We shall find that the plant is permeated with the mycelial threads of the fungus. In the beginning the fungus is restricted to the interior of the host plant, but later, having gained a foothold here, it sends its hyphæ out into the air and by coming into direct contact with neighboring undiseased plants soon spreads throughout the bed. Due to the closely packed condition of the seedlings in the bed, this is easily accomplished. As the seedlings wither and fall over they become entangled with surrounding healthy plants, and the fungus is enabled to pass rapidly from one plant to another.

An examination of the hyphæ of the fungus under the microscope discloses the presence of several different sorts of spores. Asexual spores or conidia are cut off from the mycelium, and appear as large, globose or oval bodies. These germinate by a germ-tube. Other similar structures, the sporangia, when placed in a drop of water permit the escape of their protoplasmic contents in the form of small ciliated motile spores. These swim about and after coming to rest produce infection. The conidia and sporangia except in their methods of germination resemble each other very closely. They are produced on aërial hyphæ outside the plant. Another type of spore is formed within the host tissue. Here on one of the endophytic hyphæ a small clavate or club-shaped lateral branch arises and comes into close contact with another similar branch of a more globose form. The clavate branch is the male reproductive organ, antheridium, the globose branch the female organ, oogonium. The contents of the male cell pass into the female and fertilize it. Then all of the protoplasm in the female cell rounds up into a spherical ball and assumes a heavy cellulose wall. This ball is the sexual spore or oōspore. It functions as a resting spore, and will remain in the old dead stems of the host plant or in the soil for months, and under favorable environmental conditions will then germinate. These sexual spores serve to carry the fungus over the winter in the soil, and it is by their germination that successive crops of seedlings year after year are infected. The asexual spores (sporangia and conidia) function in the spread of the disease from plant to plant or from seed-bed to seed-bed during the growing season.

Damping off may be eliminated or greatly reduced by giving attention to the methods of culture. The seed should not be sown thickly and little water should be used on the seed-bed. Allowance should also be made for the penetration of plenty of air and sunlight. If in spite of these precautions the disease is troublesome the soil should be sterilized. This can be successfully accomplished with steam under pressure. A large zinc or galvanized iron pan should be inverted over the bed and its edges forced down several inches into the soil. Steam should then be led into this from a pipe. The steam will penetrate the soil for several inches and effect sterilization. Formalin, more easily applied, is also frequently used in soil sterilization.



Oogonia, antheridia and oospores of such a fungus as the "damping-off" organism *Pythium debaryanum* These resting spores are thick-walled and resist the cold of winter.

Another fungus of great economic interest on account of its bearing upon the food supply of man is *Phytophthora infestans*. This organism causes the well-known and much dreaded "late blight" of potatoes. In its morphology this fungus is very similar to the damping off organism, *Pythium debaryanum*, and is classified in the same subgroup of the fungi, the *Phycomycetes*.

Loss to potato growers from late blight

It apparently does not, however, produce sexual spores in nature, although certain investigators claim to have developed them by growing this fungus on certain kinds of artificial culture media, of which oat-juice agar is the best known. There are a large number of diseases of the potato caused by different organisms, but late blight is the most destructive. This disease takes an annual toll of thousands of dollars from growers. Several times in history it has caused potato famines of wide extent. The Irish potato famine of 1845 was a national calamity and in 1875 the disease in England was so disastrous that the government called upon the greatest authority, Anton De Bary, for help in combating it. He studied the organism carefully and made certain recommendations for controlling the disease, but there are points concerning the life history of the fungus which are not fully understood even today.

What happens when late blight strikes the potato crop

The disease is called "late blight" to distinguish it from a less serious disease, "early blight" due to another fungus, *Alternaria Solani*, which usually attacks the potato earlier in the summer. The first symptoms of late blight may be observed upon the leaves of the plant in midsummer. The leaves lose their brilliant green hue and become mottled with dark opaque spots having a water-soaked appearance. These spots are indefinite in outline and later turn brown or even black. The affected portion of the leaf dies. On the under surface of these patches on the leaf, particularly at the margin of the spot, may be seen a white, frost-like mildew. This growth is made up of a large number of sporangiophores and sporangia which arise from the stomates of the leaf from endophytic mycelium. The sporangia are blown by the wind to other plants where they germinate during rain, forming swarm spores which infect the new host. Some sporangia fall to the ground, germinate there in the soil water, and produce swarm spores which infect the young tubers.

The disease spreads rapidly through a field, particularly in wet weather, and its daily advance from a central point of infection may be easily watched. The swarm spores which enter the tuber develop there into mycelium; and a definite sunken spot on the surface of the tuber and a reddish-brown rot in the interior soon proclaim the presence of the organism. The mycelium winters in the tuber in storage in a dormant resistant condition, and renewed growth takes place the following spring when these tubers are placed in the moist ground. When the tuber sprouts and the young plant begins to develop, the mycelium either grows up the young stem from the tuber causing general infection in all parts of the plant or it grows to the outside of the tuber and produces sporangia over its surface in the soil. These sporangia may then be washed to the surface of the ground in the heavy spring rains, or they may be brought up by worms or by the plow in cultivation. They then easily infect the lower leaves of the plant which in heavy rains beat against the ground.

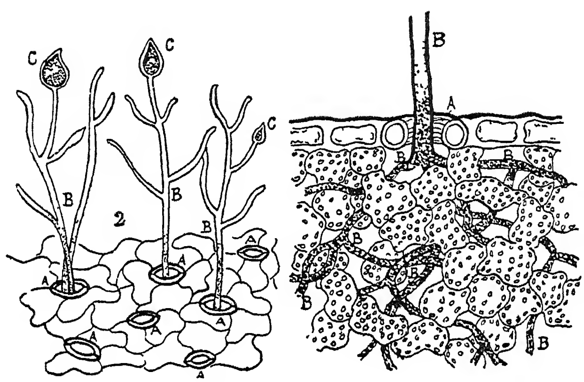
When leaves are killed or diseased smaller potatoes are the result

The mycelium of the fungus spreads rapidly in the leaves of the plant, and gives off enzymes which kill the cells of the host for a considerable distance beyond its own advance. This fact explains the rapid formation of large dead areas in the leaves. When weather conditions are unfavorable for the fungus the lesions on the leaf increase very little in extent and the disease is less destructive. The importance of the malady to the potato crop lies in the fact that when the leaves are killed or diseased, smaller tubers than normal are developed. The leaves of any green plant manufacture carbohydrate food, and in the case of the potato this is transferred to the roots and is stored there in the form of starch in large tubers as reserve food. Naturally when the leaves fail to produce this carbohydrate material, smaller tubers develop. Moreover in extremely severe cases the plant is killed. Often the entire crop of tubers is disfigured, rotted and unmarketable.

Experiments have demonstrated that some varieties of potatoes are much less susceptible to infection by this fungus than are others, and when possible these varieties should be grown. Growers who raise potatoes on a large commercial scale find it wise to spray their plants with Bordeaux mixture, and smaller growers might well follow their example. Bordeaux mixture should be applied at the 5-5-50 strength (5 lbs. copper sulphate, 5 lbs. quicklime, 50 gallons of water) and should be sprayed on the plants five to eight times during the summer beginning when the plants are six inches high and continuing throughout the growing season. Late spraying on late-maturing varieties is especially necessary. The difference in the crop clearly warrants the expense. Late blight also occurs to a lesser extent on tomatoes and certain other less important plants.

Other diseases of the potato of note are common scab, black leg, powdery scab, black wart, dry rot, leaf roll, tip burn, etc. The black wart disease is particularly destructive and has caused great losses in Europe. Our federal quarantine laws forbid the importation of this disease into the United States, but it has made its appearance in a few places.

The application of any substance as a fungicide is in the case of most diseases merely a preventive measure. In the case of Bordeaux mixture the salts of copper on the leaf serve as a protection, since copper is a poison and will kill the young germ-tubes or swarm spores before they are enabled to infect the host. After the entrance of the fungus into the plant fungicides do no good. Other methods of control such as the cutting out of diseased parts may prove effective.

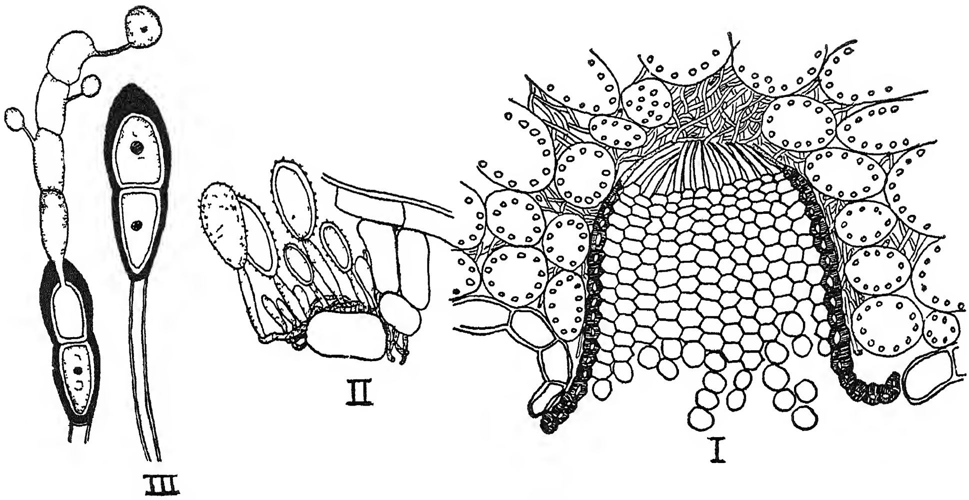


THE LATE BLIGHT POTATO DISEASE

1 Highly magnified portion of under surface of potato leaf showing filaments (*B*) of *Phytophthora infestans* protruding through stomata (*A*) and bearing sporangia (*C*) 2 Highly magnified section of potato leaf showing filaments of *Phytophthora infestans* penetrating the tissues of the leaf In doing this they absorb the nutriment in the cells.

Some plant diseases do not seem to be susceptible of control. One of these is the chestnut blight which in recent years has come into great prominence. This disease, caused by the fungus *Endothia parasitica*, made its first appearance in this country several years ago in the chestnut trees of Long Island. Its origin is a mystery. It is a very virulent parasite and soon kills the host by girdling the main branches and trunk. The mycelium of this fungus bears little flask-shaped fruiting bodies called perithecia in which the spores are developed in sacs called asci. Each ascus contains eight spores. These perithecia protrude from the bark of the tree and the spores are exuded in countless numbers. In a very few years all of the chestnuts on Long Island have been killed outright, and the disease has spread up the Hudson and into New England and Pennsylvania. Although thousands of dollars have been spent in studying the disease and the organism which causes it, no method of control has been found. Birds carry the spores of the fungus on their feet for long distances and would cross any cutting-out isolating barrier.

Another disease of great importance has recently appeared on the white pine in this country. It was imported from Germany on nursery stock of white pine and if it assumes as serious proportions here as abroad it will be one of the most destructive diseases in our forests. This fungus has two different hosts and alternates in its life-cycle from one to the other. Such a fungus is called "heterœcious". In this species one stage of the fungus appears on the leaves of the currant bush and the other occurs on the twigs or limbs of the white pine. One suggested measure of control consists in the total destruc-



THE VARIOUS SPORE FORMS OF *PUCCINIA GRAMINIS*, THE CAUSE OF WHEAT RUST

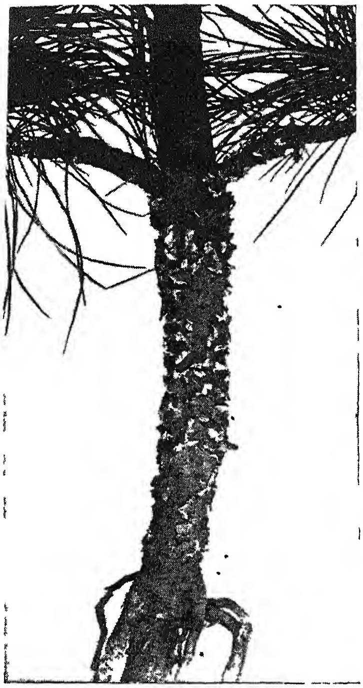
I The cluster cup on the under side of the leaf of barberry, showing the development of æcidiospores in chains These spores infect the wheat plant
II The thin walled uredospores developed on the wheat leaves during the summer The masses of these spores in the pustules on the host present the red appearance characteristic of the rust
III The thick-walled teleutospores which are developed on the wheat stems or stubble in late autumn These are the resting spores which hibernate In the spring they germinate and produce a four-celled tube, the promycelium, on each cell of which a thin-walled spherical spore is borne These spores are the sporidia They are blown to the barberry and infect it

tion of all the wild and cultivated currant bushes in the endeavor to eliminate one of the essential stages in the life history of the fungus. Infection of pines must in every case come from spores developed on the currant, and infection of the currant from spores developed on white pine. The fungus has received the name "white pine blister rust" from the characteristic blisters developed on the bark of the pine. The state of New York is endeavoring to combat the disease in its white pine nurseries and forests. The causal organism, *Cronartium ribicola*, is a member of a large group of fungi known as the rusts. Many of these are heterœcious, and many cause serious diseases of very considerable economic importance.

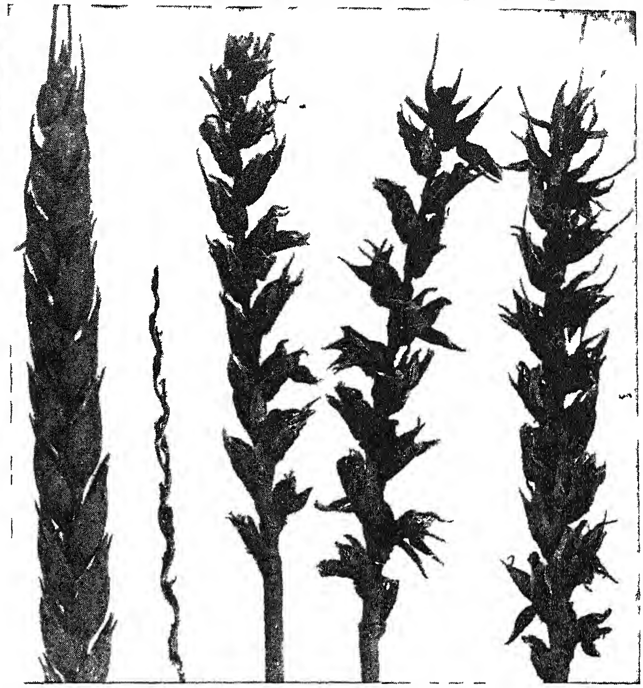
The rusts on cereals are well known. The common wheat rust, *Puccinia graminis*, passes part of its life cycle in the leaves and fruit of the barberry, a bush much used for ornamental hedges. Spores developed here later blow to the young wheat plants and infect them. The leaves and stem of the wheat soon show yellow rust-like pustules, and it is this stage of the fungus which gave rise to the name rust. In the autumn black pustules appear on the stem of the wheat and the spores contained in these, the teleutospores, are thick-walled, resting spores which enable the organism to live through the winter. These spores in the spring germinate and infect the barberry. Wheat fields affected with rust lose their healthy green color and produce smaller heads of grain. Other closely related species of rust attack rye, oats, barley, timothy and various wild grasses. The rusts as a group are very destructive, and in the aggregate reduce the value of crops in this country alone by millions of dollars a year.

The smuts are close relatives of the rusts. They produce a black, sooty mass of spores on the host, usually in the floral parts. The loose smut of oats, *Ustilago avenæ*, can be seen in almost any field of oats during the summer and will be recognized by the black powdery mass of spores in the heads of the grain. Each spore in this mass is a tiny, thick-walled, spiny, sphere. The spores are easily blown about by the wind and fall upon undiseased plants throughout the field. Many of them become attached to the seeds, and remain firmly applied to the outer seed-coats throughout the winter in the bins in a wholly dormant condition. When the seed are planted in the spring the spores

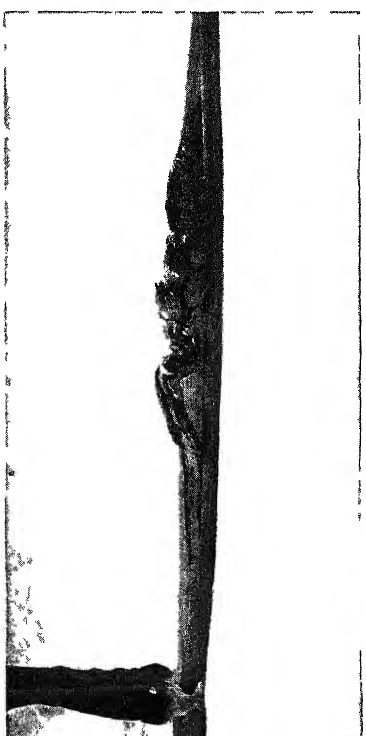
RUSTS AND SMUTS THAT BLIGHT PLANTS



The white pine blister rust, showing the typical pustules of rust spores.



Wheat smut The head of grain to the left is normal, the others badly smutted The causal organism is *Ustilago tritici*



Oat smut The causal organism is *Ustilago avenæ.*

Fire blight of apple due to *Bacillus amylovorus* A badly blighted and blackened twig contrasted with a healthy one

germinate and infect the seedlings, forming in them a mycelium which grows upward through the developing plant and produces the mass of spores in the head at maturity. The spore masses replace the ovaries and other floral parts.

Oat smut may be prevented by treating the seed before planting with a solution of formalin made by diluting one pint of the commercial solution with fifty gallons of water. The oats should be placed on a clean barn floor, and the formalin should be sprinkled over them as they are being shoveled over. One gallon of this solution should be used for one bushel of seed. The oats must be mixed thoroughly, then shoveled into a pile and covered with canvas. After standing in the pile for four hours the oats if they are to be drilled must be spread out and allowed to dry. They can be sown by hand without drying. One extra peck for each bushel should be allowed to offset the swelling of the grain.

Other species of smut attack wheat, corn, barley, rye and other cereals. The life-cycles of different species of smut show essential differences, and the control measures recommended vary in consequence. The common loose smut of wheat passes the winter in the mycelial condition inside the wheat grain rather than as a spore on its surface. For this reason treatment with formalin is of no avail since a solution strong enough to penetrate the grain and kill the fungus would also kill the germ of the wheat. It has been found, however, that seed may be treated successfully with hot water at 54° C. (129.2° F.) for ten minutes; the fungus mycelium will be killed but the more resistant wheat germ will still live. It is necessary in the use of this method of treatment to give the seed a preliminary soaking for about six hours in cool water at ordinary room temperature. This starts the mycelium of the fungus into renewed growth and renders it easier to kill than in the dormant condition. The wheat seed should be placed in small loose sacks or wire baskets not holding over one-half peck each. It is of great importance that the seed be treated in small lots in order that all the grain may be quickly brought to the temperature of the water. In attempting to use large lots the grain at the center remains cool longer and receives an insufficient treatment, while a longer treatment than that recommended may kill the grain. The hot water method of seed treatment is not easy to use but when the directions are carefully followed good results are obtained.[1]

Other smuts require other treatments. Corn smut cannot be controlled by any type of seed treatment since the fungus hibernates in the soil.

The bacteria known to all of us as the cause of many diseases in animals and man are also the cause of diseases of plants. In fact there are many more plant diseases due to bacteria than there are animal diseases due to these minute organisms. Bacteria parasitic on plants cause characteristic diseases. In many of these pronounced wilting or blighting of the foliage takes place, and to these manifestations the names "bacterial blight" and "bacterial wilt" are commonly applied. In other cases soft rots of various plant parts, such as the fruit, roots and tubers, takes place. More rarely woody galls or corky excrescences are formed.

The "fire blight" disease of apple, pear and quince, caused by *Bacillus amylovorus*, is one of the best known bacterial diseases of plants. In this instance the bacteria are disseminated by bees, flies and other insects, and the disease cannot be controlled by spraying. The twigs are killed and the leaves blacken and die but do not fall from the tree. This results in the blackened appearance of the foliage of the tree which has given rise to the name "fire blight". This is a difficult disease to control, and a diseased tree can only be saved by prompt cutting out of all infected twigs or limbs. Even these drastic methods frequently fail, and in some sections of the country where climatic conditions favor the rapid development of the disease, pears or quinces cannot be satisfactorily grown. The disease on apples is somewhat less destructive.

[1] Either of the following bulletins will give all the detailed information necessary.

Bulletin 152, Bureau Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

Bulletin 283, Cornell University Agricultural Experiment Station, Ithaca, N. Y.

The organism causing crown gall in plants occurs upon a wide variety of hosts. The disease produced manifests itself in the development of large galls on various parts of the plant. Since these frequently occur at the base of the stem near the ground at the crown of the plant the name "crown gall" has been applied. These galls in many respects resemble cancer, and the careful study of this disease may prove of value in connection with the study of this dread scourge of man. Investigators have produced large galls by artificial infection on beet, raspberry, tomato and many other hosts.

Other plant diseases caused by bacteria which are worthy of mention are the black rot of cabbage, the soft rot of carrot and certain other vegetables, the streak disease of the sweet pea, the soft rot of the hyacinth, bean blight and the wilt of cucumber and muskmelon.

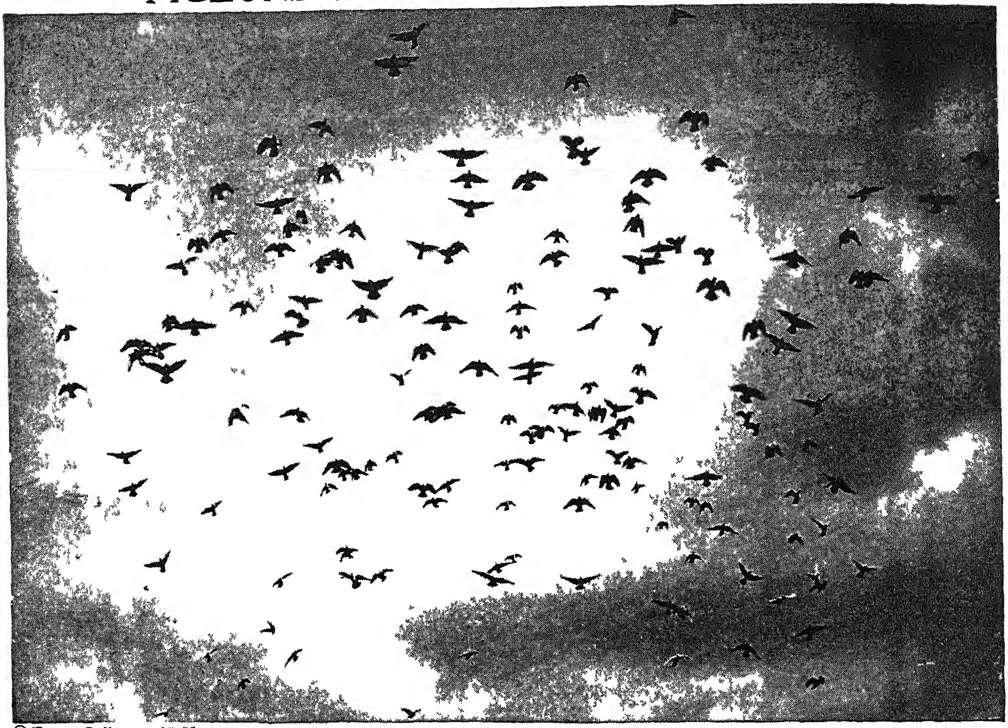
The group of organisms known as the "slime molds" are very low in the scale of life; so low in fact that in one stage of their existence they live as naked masses of protoplasm, called "plasmodia". In this state they infest solid food material like an amœba and move about with a streaming motion. They seem to lie on the border line between plants and animals and cannot be certainly said to be either. The great majority of the species are saprophytes occurring on old logs, stumps, sawdust piles, rotting leaves, etc., but a few species are parasites of considerable economic importance.

The club root of cabbage is caused by a slime mold, *Plasmodiophora brassicæ*. This is the most serious disease of cabbage with which growers have to contend. The roots are greatly hypertrophied and deformed, and soon crack open. Decay organisms then gain an entrance, and the root becomes putrid and foul smelling. The normal development of small roots is retarded, and the plant above ground failing to obtain a normal supply of food from the soil is stunted. The leaves are underdeveloped and a head is not formed. The parasite lives in the soil for a number of years, and land which has once produced a diseased crop should be avoided for cabbage, cauliflower and other related plants. Manure containing cabbage refuse should not be used, and crop rotation if practised must avoid the repetition of cabbage on infested land within five years. Only healthy plants should be set out. If the use of infested land is imperative then a good quality of stone lime should be applied evenly over the land at the rate of three tons to the acre, and this application should be made eighteen months before planting. An acid soil favors the development of the parasite

Another slime mold disease of importance is the powdery scab of potato caused by *Spongospora solani*. This disease is easily recognized by the little pustules filled with brown powder which are formed over the surface of the tuber. This powder is a mass of the spores of the organism. This disease is very destructive and infected areas should be quarantined. It is not yet a serious menace in this country. Only clean tubers should be planted.

Few of the algæ are parasites, but a common disease of the tea plant called red-rust is due to a member of this group.

Of the parasitic flowering plants mistletoe and dodder are the best known representatives. Mistletoe occurs as a parasite on trees, and dodder is a serious pest in fields of alfalfa and clover. In each case the parasite sends large haustoria or suckers into the tissue of the host plant and thus obtains its food. Alfalfa fields attacked by dodder show the plants dying in small more or less circular areas. In these areas the ground is covered with a tangled mat of yellow threads of the diameter of heavy twine. These are the dodder stems. These threads wind about the host plants, send in haustoria and soon kill them. Infested spots should be mowed closely. Then the stubble should be sprinkled with kerosene, covered with dry hay and burned. In planting alfalfa and clover only seed free from dodder seed should be used. The seed can be cleaned by sifting it with a sieve made of No. 34 wire, with twenty wires to the inch. Any state agricultural experiment station will analyze free any seed sent to them. All inquiries regarding plant diseases should be addressed to the plant pathologist.



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FLOCK OF PIGEONS IN FLIGHT AT SAN DIEGO

Photo Ewing Galloway, N Y

FEEDING THE PIGEONS ON BOSTON COMMON

OUR COMMON BIRDS IV

Doves and Pigeons, Cuckoos, and Wood and Water Kingfishers

GENTLE DOVES AND CRESTED KINGFISHERS

THERE is no real difference between doves and pigeons "Dove" is ordinarily applied to the smaller species but often the two words are used interchangeably.

In general, pigeons and doves (family *Columbidæ*) can be distinguished from other birds by their small heads, heavy bodies and compact plumage. They have slender bills which are swollen at the tip and covered at the base by a soft fleshy skin called a "cere" Their wings are long and pointed, but their legs are relatively short, so that while they are extremely strong fliers, they walk with short mincing steps. Their tails are always well developed and may be either square or rounded at the tip. Often the name "pigeon" is restricted to the square-tailed and that of "dove" to birds with rounded or pointed tails, but this is by no means constant, the passenger pigeon, for example, having a decidedly pointed tail.

There are about six hundred and fifty species of pigeons and they are found in all parts of the world except arctic and antarctic regions, being most abundant in the tropics, especially in and about the Malay Archipelago, where possibly they may have originated. Because of their defenselessness they are particularly adapted to island life where enemies are few. This may account for their great abundance in the Polynesian Islands and also for the brilliant and conspicuous plumage of many of these island species, reds, greens and purples occurring in wonderful combination, in contrast to the majority of continental species which are bluish or brownish.

Isolation likewise accounts for such anomalous pigeons as the extinct dodo and solitaire of Mauritius and Pedriguez. These curious, heavy-bodied birds had entirely lost the power of flight because of the absence of terrestrial enemies on the islands which they inhabited. This made them an easy prey for the first explorers, causing their early extermination.

In size, pigeons vary from the tiny ground doves, some of which are smaller than sparrows, to the crowned pigeons which measure from two to nearly three feet in length, or the extinct dodo which was described by its discoverers as "bigger than our swans". They vary also greatly in habits, and in the choice of their haunts Some species live in large flocks, while others are solitary; some inhabit the dense forests, others the open plains; some are terrestrial and rarely fly, while others are arboreal and among the strongest fliers Most species disband during the nesting season but the passenger pigeon, now extinct, nested in colonies of immense size

The nests are crude affairs, built of sticks, with little shape and no lining. The eggs are pure white and usually two in number. The young are naked when hatched and perfectly helpless. They are fed by regurgitation during the entire time they are in the nest, and indeed until they learn to eat by themselves The food of the parents consists largely of seeds or grain which is stored in an extremely large, two-lobed crop, and there softened and partially digested. This curdlike mass, mixed with a secretion from the wall of the crop and called "pigeons' milk", is injected into the throat of the young bird.

In drinking, pigeons differ from other birds in that they do not raise the head in order to swallow but keep the bill immersed until the draught is finished.

Of the true pigeons, the domestic variety is naturally the best known. The parent species is the rock dove which, in the wild state, inhabits the rocky coasts of Europe from the Faroes to the Cyclades, nesting in caverns. In the domestic state, it has been carried to all parts of the world and more than one hundred and fifty different kinds which breed true are now recognized by fanciers. In the United States, the only surviving species of true pigeon is the band-tailed pigeon of the Rocky Mountain region, and it is becoming rare in many places. It is a bird nearly the size of the domestic pigeon and somewhat the same color, but with a white band on the back of the neck and a light gray band on the end of the tail. It feeds largely upon acorns, young sycamore balls and wild berries and normally confines itself to the mountains, although sometimes, if food is abundant, it frequents larger river bottoms in large flocks.

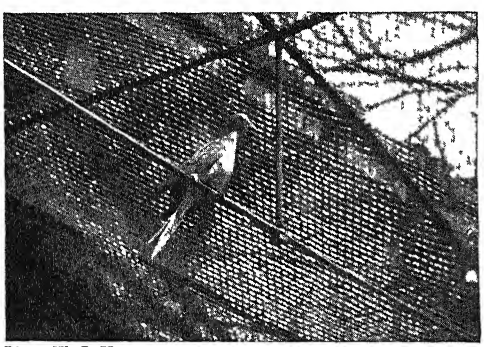


Photo W. C. Herman

THE LAST OF THE PASSENGER PIGEONS

If we omit the white-crowned pigeon of the Florida Keys and the West Indies, the only other true pigeon indigenous to the United States and Canada was the passenger pigeon, now extinct. The vast flocks which during the last century darkened the sky for hours or even days at a time, are no more. The last survivor of the whole race died in the Cincinnati zoölogical park, September 1, 1914. Rewards of several thousands of dollars have since failed to bring to light a single living specimen of this splendid bird.

Alexander Wilson, writing about 1808, estimated that a flock observed by him near Frankport, Kentucky, numbered over two billions; and a nesting colony near Shelbyville, in the same state, extended through the woods for nearly forty miles and was several miles in width, every tree of suitable size being loaded down with nests, the larger trees containing from ten to forty. Their nocturnal roosts, at other seasons of the year, were nearly as impressive. Nuttal in describing them states: "Nothing can exceed the waste and desolation of the nocturnal resorts; the vegetation becomes buried by their excrement to the depth of several inches. The tall trees for thousands of acres are completely killed, and the ground completely strewed with massive branches torn down by the clustering weight of the birds which have rested upon them. The whole region for several years presents a continued scene of devastation, as if swept by the resistless blast of a whirlwind." The last wild birds of which we have any definite record were shot on September 14, 1898, one in Michigan and one in New York.

During the ninety years from the time Wilson wrote until the species disappeared the birds were netted and shot by the thousands and shipped in carloads or even train loads to the markets or fed to the hogs. Not content with netting and shooting, the market hunters went to the nesting grounds with clubs and fires and sulphur pots and killed the birds on their nests. At one nesting place in Michigan, five hundred netters were at work and their average catch was 200,000 birds each, and at another it was estimated that fully a billion birds were accounted for. The laws, at that time, gave them no protection because, as stated in some of them, it was considered that they were so numerous that the inroads of man could have no appreciable effect upon their numbers. And now they are gone. The last nesting known in New York state occurred near Olean in 1868, in Michigan in 1881. Perhaps, we may learn from the mistakes of our fathers and, though we have lost this species, we may yet save others that are following it to extinction.

The mourning dove, though it is put in a different family or sub-family, appears like a small edition of the passenger pigeon. Indeed, when the rewards were offered for the discovery of a passenger pigeon, numerous claims for it were made by non-observant persons who had discovered mourning doves.

The notes of most wild pigeons are soft cooing sounds and those of the mourning dove are even more gentle and mournful than others. This has given rise to its name.

The turtle dove, a species that is often seen in captivity in this country, is native throughout Europe during the summer, retiring to northern Africa for the winter. It is quite similar to our mourning dove, being fawn color but with a larger black mark on the sides of the neck.

The cuckoos

To one interested in the habits of birds, the members of the cuckoo family (*Cuculidæ*) present some of the strangest paradoxes of all nature. Constancy and maternal devotion, symbolic of bird life, are with some of the species replaced by promiscuity and parasitism; and the privacy of nest life, for which most birds risk the hardships and dangers of long migrations, is forsaken by some cuckoos for a communal habit. The majority of Old World species, for example, build no nests of their own but lay their eggs in the nests of other birds, where they are hatched and the young brought up by the foster parent. The New World species called anis, on the other hand, build a common nest in which several families lay their eggs and then share the duties of incubation. A few cuckoos, and among them the common American species, do not depart widely from the common habit of birds, for they build nests and raise their own young.

There are about one hundred and ninety species in the cuckoo family, found all over the world, though most abundant in the tropics. About thirty-five species are found in the New World but only two of these are common north of Mexico, the black-billed and the yellow-billed species. The road runner, however, which is fairly common in some parts of the arid Southwest, likewise belongs to this family. The California cuckoo is but a larger representative of the yellow-billed species, and the mangrove and Maynard's cuckoos and the anis are tropical species that occasionally wander to our Gulf Coast.

MOURNING DOVE AT ITS NEST WITH YOUNG

In general, cuckoos are medium-sized, dull brown, gray or black birds, although there are some exceptions among the African golden, and the violet and emerald cuckoos, which are beautifully iridescent. Almost as strange as their parasitic habit is the simulation by many species of

NEST AND EGGS OF MOURNING DOVE

cuckoos, of the plumage of the smaller hawks or of the birds which they parasitize. Thus the common European cuckoo and the hawk cuckoos of Asia resemble so closely the common small sparrow hawk as to alarm all small birds by their approach. The drongo cuckoos of India,

The photographs on this page and subsequent pages of this chapter are from negatives by A. A. Allen.

on the other hand, resemble the drongo shrikes, which they parasitize, even to the extent of having the outer tail feathers curved outward, both birds being uniformly black.

The cuckoos are rather low in the scale of bird life, lying between the parrots and kingfishers Even a superficial examination shows their difference from ordinary perching birds, because, instead of having three toes directed forward and one backward, there are two forward and two backward, as in the parrots and woodpeckers.

Unlike the young parrots, the cuckoos do not pass through a downy stage but are almost naked when hatched, being extremely ugly black-skinned little creatures with a bare scattering of threadlike feathers. The growing feathers remain in their sheaths until fully developed so that for a long time their bodies seem incased in tiny lead pencils. When the feathers are fully developed, the quills burst open at about the same time so that the change from the curiously mailed creatures to the light fluffy fledglings takes place in a very few hours.

The common cuckoo of Europe, and there are about a dozen very similar species, ranging through Europe and Asia except Polynesia, are about ten or twelve inches long, brown or gray above and barred below, with long fan-like tails and pointed wings that give them a swift, hawk-like flight. As a result, they have been much persecuted by gunners and game-keepers so that they have become very wary and are seldom seen even where their notes are a familiar sound.

The notes of the common European cuckoo, so familiar to everyone because of the old-fashioned clocks of that name, are always associated with the coming of spring, for the cuckoos are migratory, spending the winter in Africa and returning to Europe among the first of the spring birds. For this reason, in spite of its parasitic habits, it has become a great favorite. Thus Wordsworth writes:

"O blithe new-comer, I have heard,
I hear thee and rejoice.
O Cuckoo, shall I call thee Bird,
Or but a wandering voice?"

The birds parasitized by the cuckoo include most of the species smaller than itself whose nests it is about to discover. Apparently the egg is not laid directly in the nest, for many reliable observers record having seen the cuckoo deposit its egg on the ground and then carry it in its bill to the selected nest. The eggs of the cuckoo are small for the size of the bird, but larger than those of the host. They vary in color from a dull greenish to a dull reddish-gray with spots and mottlings of darker shade. Some authorities claim that the color of the eggs is hereditary and that a cuckoo always parasitizes the species in whose nest it was raised and whose eggs its eggs most closely resemble. Other authorities disagree, however, and there is as yet no proof one way or the other.

However that may be, no sentiment is wasted either by the old cuckoo or by the young, for once the egg is laid, the old bird never comes back to it, and when it has been hatched by the foster parent the young cuckoo works the rightful young or unhatched eggs on to his hollowed back and heaves them overboard. The parasitized birds, except for some outcry at the first appearance of the cuckoo, once the egg is laid, never seem to realize the calamity that has befallen their own young but take pride in filling the cavernous mouth of the young stranger.

In the New World cuckoos the parasitic habit is not developed, although all species are rather shiftless nest builders and occasionally drop their eggs in each other's nests or, very rarely, in the nests of other birds. Thus in the accompanying photograph of the nest of a black-billed cuckoo, the larger egg is one of the yellow-billed species. Another evidence of a possible former parasitic habit among the American cuckoos, or a leaning in that direction, is that the eggs are not always laid at regular periods, one each day, as with normal birds. Intervals of several days sometimes elapse and a nest may even contain young birds and fresh eggs. The eggs are pale greenish blue, those of the black-billed species being smaller and darker.

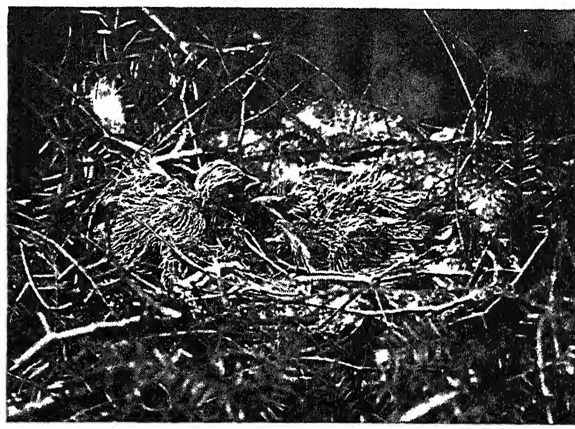
The parasitic habit of the Old World cuckoos, however, is developed in the New World in a totally unrelated family, the *Icteridæ* or blackbirds. In this family, the majority of species are expert nest builders and show all the constancy and parental instincts of normal birds, but one rather large division, the genus of cowbirds (*Molothrus*) has departed so far that, with one exception, the habits of its members are similar to those of the European cuckoo. There is this difference, however, that the eggs are laid directly in the nest of the smaller bird.

The American black-billed and yellow-billed cuckoos are very similar in general appearance, being long slender birds, dark brown above and pure white beneath. The long tail feathers bear white spots at the tip, those of the yellow-billed species being more conspicuous. This and the yellow lower mandible, together with the red eye ring of the black-billed species, are the most distinctive differentiating marks.

The cuckoos frequent open woodlands or the borders of woods, and sometimes come into orchards and gardens, where they are of inestimable value because of their fondness for tent caterpillars and other hairy larvæ that are so destructive to foliage and that, when full grown, are shunned by most birds. They are usually shy, retiring birds and are very easily overlooked because of their habit of remaining absolutely quiet when alarmed. In flying from tree to tree, they have a graceful sweeping flight, though they seldom fly long distances through the open. In keeping with their retiring habit, their migrations, which carry them to South America, are performed entirely at night.

The notes of the two species are so similar that one cannot always distinguish between them. The song of the yellow-billed species has been represented by Dr. Chapman as: tut-tut, tut-tut, tut-tut, cl-uck-cl-uck, cl-uck-cl-uck, cl-uck, cow, cow, cow, cow, cow, cow, cow. The song of the black-billed species is somewhat softer and the cow-cow notes are not usually run together. The last part of the song is quite similar to that of the mourning dove, and indeed the bird is quite dove-like in many ways. A curious superstition declares that their songs predict rain, and this has given them the name of "rain crows" in many parts of the country.

NEST OF BLACK-BILLED CUCKOO



YOUNG BLACK-BILLED CUCKOOS IN THE NEST

The nest with eggs contains one of the yellow-billed and three of the black-billed cuckoo

The anis, which have been mentioned as having a communal habit, are among the most familiar sights of the West Indies or of the open land and clearings of tropical America where they are known as "savanna blackbirds" or "tick birds". They are typically pasture birds where they sun themselves with wings half spread on the tops of bushes or follow the cattle, catching the insects which they disturb in the grass or pecking the ticks from their backs. There are three species of anis, all of them uniformly black with some metallic reflections and with large com-

pressed bills that give them a curious parrot-like profile. In other ways, however, they are far from parrot-like. They are weak fliers and their long tails are composed of but eight feathers, the smallest number which any bird possesses.

When the nesting season arrives, each company commences building a nest, usually in the top of a small tree. It is a bulky affair, about the size of a crow's nest, made of sticks and green leaves. In it the various females lay their eggs, and if there is not enough room for all the eggs, green leaves are placed over the first layer and the rest of the eggs are laid on top. The lower ones usually do not hatch and the upper ones are sometimes laid at such different intervals that fresh eggs and young birds are found in the same nest. The exact apportionment of duties between the females has not yet been discovered, but it is believed that they all help in incubating and in feeding the young.

Another curious and entertaining bird of the cuckoo family is the road runner, or "snake killer", of Mexico and the arid regions of our Southwest. It is sandy-brown in color, broadly streaked, and nearly half of its two feet in length is taken up by its enormously developed tail. Its long legs permit it, without the use of its wings, to cover the ground about as fast as a horse can trot. In fact it never flies unless hard pressed but often darts out into the road in front of a horse and easily keeps ahead until it gets tired out, when it disappears into the brush, throwing its long tail over its back to act as a brake.

In food habits, the road runner is omnivorous, eating caterpillars, beetles, cactus fruits, horned toads, lizards, snakes and young birds with equal avidity. Many wonderful stories are told of its strange ways with rattlesnakes, and surely its curious appearance is sufficient for any number of strange yarns. One has it that when a road runner discovers a rattlesnake coiled up asleep, it builds a corral of thorny twigs about it and then drops one upon the snake to awaken it. The startled snake thrashes about in its effort to escape, fills its body full of thorns and soon falls prey to the road runner.

Its nesting habits are quite normal, for it usually builds a rough nest of twigs in a thorny bush and lays from four to nine white eggs. Sometimes it utilizes the deserted nest of another bird. The young birds are easily tamed and make fine pets, seeming to become attached to their captors.

In general, cuckoos, even the parasitic species, are valuable birds because of their great capacity for destructive caterpillars, and it is unfortunate that superstition or popular prejudice is against them. In Europe, there is a belief that they transform into hawks in the winter, and nearly everyone shoots them on sight. In this country, our species suffer less and are fully guarded by our laws but many ignorant persons still shoot them.

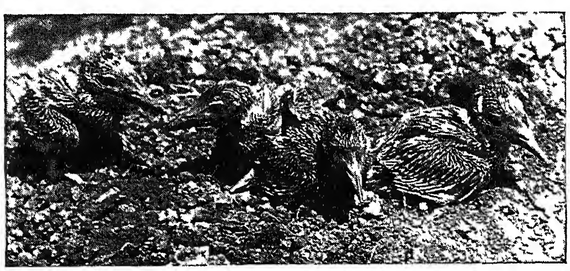
The kingfishers

Whether sitting patiently on a branch overhanging the water or dashing up the stream with a wild rattling cry, the kingfisher always demands attention. His curious shape, due to his large crested head, long bill and short tail, his striking coloration, his interesting habits and the natural charm of his habitat, all combine to make him one of our most attractive and best-known birds. It is the same the world over. The members of the kingfisher family (*Alcedinidæ*), of which there are nearly two hundred species, are beloved by all people. It is little wonder that many legends have grown up about them. The Halcyon Days of Greek mythology, for example, were the fourteen days in winter when Æolus, the god of the winds, kept the weather calm so that the floating nest of the kingfisher could ride safely over the sea. The birds themselves were Ceyx and Alcyone, the latter the daughter of Æolus, whom Zeus had changed into kingfishers. In the days of Shakespeare the dried body of a kingfisher was supposed to keep moths from woolen garments or, if suspended from the ceiling, to point its bill in the direction of the wind.

While the kingfishers are almost all brilliantly colored, they are not all alike in habits but are divided into two natural groups, the wood-kingfishers and the water-kingfishers. The former frequent

woodlands, open country, or even gardens, where they feed upon insects, crustaceans, frogs, lizards, sometimes small birds and mammals, and only occasionally take fish. The latter group, like our American bird, frequent streams and lake shores and feed almost entirely upon fish, although frogs, crayfish and aquatic insects are sometimes taken. The majority of the wood-kingfishers are extremely brilliant, metallic greens and blues, satiny whites, russets or reds predominating. One genus of about twenty species, found in India and the Malay Archipelago, have elongated central tail feathers which are enlarged at the tip, or racquet-shaped. One of the largest and best-known species, however, is much duller. This is the famous laughing jackass of Australia and New Guinea, a bird nearly as large as a crow but having a much heavier bill. It is brown above and grayish white below, this color extending around the neck and in a broad band over the eye. A little greenish blue on the lower back and in the wing enlivens the otherwise plain attire. The name is derived from its loud gurgling, laughing note which sounds "as if a troop of fiends were shouting, whooping and laughing" about one. It is a tame, stupid bird and rather inquisitive, coming about camping parties and watching all that transpires with apparent interest.


FEMALE KINGFISHER, WITH SMALL FISH FOR ITS YOUNG


YOUNG KINGFISHERS IN THEIR PARTIALLY GROWN FEATHERS

The common kingfisher of Europe, and the only one found in the British Isles, is one of the water-kingfishers with habits much like our American bird. It is much smaller, however, only seven inches long, and more striking, being bright azure-blue above and rusty orange-red beneath It is considered the most brilliant of the British birds.

All kingfishers nest in holes, mostly in perpendicular banks of streams, but some species nest in walls, trees or stumps, and all lay pure white eggs. Usually no nest is built, although sometimes a few straws or bones of the fish which they have eaten cover the floor of the cavity.

Young kingfishers are naked when hatched, lacking even the sparse down which is characteristic of most young birds. They likewise omit the juvenile plumage, for the first feathers which they wear are those of the adult birds. As with young cuckoos, the feather sheaths do not break open until the feathers have nearly matured, and, for a time, their bodies are incased in the same curious coats of mail.

With most species of kingfishers the males and females are very similar or the females may even be a trifle brighter than the males. This is very uncommon among birds, for if a species is brilliantly colored the bright feathers are usually found only on the male and the females are much duller. With birds that build open nests this is necessary, for bright colors would call attention to the female while incubating and result in her destruction. With birds that have always nested in cavities, so that the female is entirely out of sight while on the eggs, there is no such need for protective coloration and the females are often brilliant.

Among our American birds we find this to be the case with the woodpeckers as well as the kingfishers. Among tropical and Old World species there are many, such as the trogons, toucans, hornbills, bee-eaters, rollers, etc., in which the females are as bright as the males. These birds have probably always nested in cavities and never developed the nest-building instinct.

All of the New World kingfishers, and there are but seven species, belong to the fish-catching group. They are either blue or bright green above, and white or russet below and vary in size from the little South American orange-and-green kingfisher, which measures scarcely five inches in length, to the large ringed kingfisher that occurs as far north as southern Texas, and measures sixteen or seventeen inches.

The only species found in North America, north of Texas, is called the "belted kingfisher". It is about thirteen inches in length, but, because of the shortness of its tail and the heaviness of its body, it appears larger than the measurement would suggest. It is found in summer along streams, or about lakes and ponds, from northern Alaska to the Gulf, and in winter commonly from Ohio to northern South America. Occasionally it winters as far north as New York or New England, where it can find open water.

The kingfisher is bluish gray above and white below, the white of the underparts extending around the neck in a broad ring. Across the breast and down the sides is a bluish gray band which, in the female, is tinged with rusty. The female, moreover, has a secondary band of rufous below the gray band. The head of both the male and the female has a curious double or interrupted crest which is always erected when the bird is alarmed or nervous.

The kingfisher has two methods of fishing, either waiting on a branch or projecting rock over the water for its prey to swim beneath, or flying rather high over the water until it locates a fish swimming near the surface, when it hovers for a moment on rapidly beating wings. In either case the plunge is made head foremost, with closed wings, and the fish is speared with the sharp, javelin-like bill. The bird itself is carried entirely beneath the surface of the water by the force of the fall, but, rising immediately, returns to its former perch, juggles the fish about until it gets the head directed downward and swallows it entire. The size of the fish which can be swallowed is quite surprising. The indigestible bones and scales are later ejected from the mouth, much as in the owls, in the form of pellets.

The kingfisher always nests in a hole drilled into the perpendicular bank of a creek or sometimes far from water in a gravel pit or railroad cut. The hole is usually within a few feet of the top of the bank and is directed inward and upward for from four to ten feet and enlarged at the end. No nest is built, but the bones of fish which it has eaten often line the cavity. In drilling the kingfisher uses its bill and pushes the soil out with its feet.

Kingfishers are wary birds and, no matter how carefully approached, will permit one to reach only a safe distance before flying off, with a loud rattling cry, to their next perch. They usually have a number of favorite perches along a stream but their hunting range is rather limited and when frightened upstream from one perch to another, they soon make a wide detour back to their starting point. Their flight is strong and direct, and when coming head-on is so very duck-like that hunters have been known to fire at them, thinking until too late that they were ducks.

About trout streams or artificial ponds where valuable fish are being raised, the kingfisher is sometimes quite destructive to the young fish. It is therefore not protected by law. In most places, however, the fish taken are minnows or suckers or others of little or no commercial value. The kingfisher is far too picturesque a bird to warrant wholesale destruction. Even the most careless gunners and the most inveterate fishermen seem to have a wholesome, friendly interest in this little pirate of the stream, so that relatively few are shot for the mere sake of killing. It is probably for this reason, in addition to its wariness, that it is still a common bird wherever there are suitable conditions for food and nesting.

THE ORIGIN OF THOUGHT

Man's Growth as a Thinker through His Superior Brain-Facility for the Association of Ideas

THE PUTTING OF TWO AND TWO TOGETHER

WE have found, on comparing the cortex of the human brain with that of the nearest mammal, that its very much greater size depends, in only relatively small degree, upon the enlargement of those areas to which we can assign definite functions. The greater part of the enlargement is due to the separation of these areas by large portions of the cortex to which we can assign no special function, but which must surely be of high importance, since they, above all, distinguish the human cortex from its inferiors. On microscopic examination of these areas and their connections we find very definite evidence. All nerve fibers which proceed from them do not run to the spinal cord, on their way to some relation with the body, nor do they go to the cranial nerves, which control the movements of the eyeballs and so forth. Some go to other parts of the cortex itself, and there they end.

As for the nerves which come to these areas and end around their cells, they are found to come from other brain areas. In a word, these are clearly association areas. They connect all parts of the brain with all other parts. They have no other function, and they are called the "silent" areas, because they yield no reply on stimulation, but their function is, in some ways, the highest and newest of all. This does not mean, of course, that no animal has association areas, or is incapable of the process of putting "two and two together", which we are about to study. But the most characteristic fact of the human brain, in respect to function, is just its unique development of the faculty of putting two and two together, which we shall see to be practically equivalent to what we call thinking. We thus have what appears to be a thoroughly satisfactory correspondence between a special characteristic of structure and a special characteristic of function.

The reader will be tempted to assume that these do really account for each other, and that the process of thinking does just consist of the sending of impulses through the systems of association fibers from one part of the cortex to another. No doubt that is involved, but close examination of this idea will show that it is much too simple. When we look at the processes of, say, mathematical reasoning, we really cannot get them to correspond to our picture of the brain, with its association areas and systems of fibers Still, their unique development in the human brain remains, and we may be sure that it somehow plays an important part in thinking.

A better and deeper interpretation of these association areas is now available. Examination of them and their fibers at early ages shows that they are very late in development — which corresponds, of course, to the fact that they occur last in the history of the evolution of the brain. No doubt their function must be very high, and specially human. We find, further, that there is an element of modifiability, inconstancy, almost "fluidity", in the structural arrangement of these parts, contrasting with the rigid, constant structure of lower and older parts of the brain, which are laid down in a fixed fashion, practically identical in all individuals, long before birth. Now, there can be no

doubt as to the great human characteristic which corresponds to these facts. It is the power to learn. This is sometimes called educability, sometimes docility, but it is, at any rate, that great characteristic of man in virtue of which he learns by experience, and so adapts his behavior, to a degree which is without parallel in the animal world, and which essentially accounts for his dominance in the scale of nature.

Lankester introduced this term "educability", in 1899, and, though it is clumsy, it is expressive. In his Romanes Lecture, a few years later, he returned to the subject, asking to what the increased bulk of the brain in man, and to a much less degree in the latest forms of various other mammals, was due. The smaller, older brain is perfectly efficient; its possessors "carry on a complex and effective life of relation with their surroundings".

The true significance of the increased bulk of the human brain

"It appears that the increased bulk of cerebral substance means increased 'educability' — an increased power of storing up individual experience — which tends to take the place of the inherited mechanism with which it is often in antagonism. The power of profiting by individual experience — in fact, educability — must in conditions of close competition be, when other conditions are equal, an immense advantage to its possessor. . . . It is obvious that the opportunity for those individuals with the most 'educable' brains to defeat their competitors would arise. No marked improvement in the instrument being possible, the reward, the triumph, the survival, would fall to those who possessed most skill in the use of the instrument. And in successive generations the bigger and more educable brains would survive and mate, and thus bigger and bigger brains be produced. . . . The result is that the creature called Man emerged with an educable brain of some five or six times the bulk (in proportion to his size and weight) of that of any other surviving brain."

Such is Lankester's account of the human brain.

The newer association areas of the brain the parts that make men educable

And all the recent psychologists are in agreement with him, and teach us to regard the association areas as essentially the organs by which man learns. Here, for example, is a recent statement: "There is present at birth a vast number of nervous elements which become only gradually organized, modifying and combining the congenital systems in extremely complex systems which constitute acquired dispositions to modes of action peculiar to the individual. The number of the elements of this nature is so great that the areas of the cortex of the cerebrum in which they predominate, those which surround the various sensory areas and are known as the association areas, are considerably more extensive than the sensory areas, which in the higher animals make up the greater part of the cortex. The greater relative size of the brain of man is chiefly due to the development of these parts. The very great capacity for learning by experience, rendered possible by this vast mass of nervous elements not congenitally organized, distinguishes the mind of man, and raises it immeasurably above that of the highest animals."

Of course, very special attention has been directed by anatomists and students of development to these areas and systems upon which the supremacy of the human brain, and therefore of man, depends. Some of them, for instance, which are closely associated with voluntary movement, and its "educability", can be shown to be much smaller in apes than in men, still smaller in the dog, scarcely visible in the rabbit, and entirely absent in the lower vertebrates. The reader will remember Bergson's demonstration of the *unlimited* character of the human brain, which can make new instruments for life, and is not confined to those which the body of man itself comprises. Here we see the anatomical structure which corresponds to this power of the human brain.

It has already been mentioned that these parts of the brain are late in reaching their full development.

The association areas of the brain not fully laid down till adolescence

This question has been specially studied by a famous German embryologist, Paul Emil Flechsig. Most nerve fibers run in a white or medullary sheath of what is perhaps an insulating material, which keeps the current in its place. However that may be, we are sure that nerve fibers which are destined to have this sheath, or ' medulla", do not perform their functions until its appearance. In the brain of an infant very many fibers are already properly medullated, and can do their work, or of course the infant could not live. But many are not. Study along these lines helps us to distinguish various tracts in the brain, and to define their order of development; indeed, we owe most of our knowledge of the association systems to Flechsig and this method. He has shown us that, at birth, the association system is very imperfectly developed, and that some parts are actually not laid down in working order until after adolescence. They are thus last to come, alike in the history of the race and of the individual. Their non-development is probably responsible in large degree for the non-educability of the feeble-minded and other defective types of brain. Their owners can only learn to a very limited extent, and remain children, or lower, all their days, so far as mental capacity is concerned.

So much for the anatomists. Let us now look more closely at the psychical side of this question. The anatomists can help us no further; what we now require is introspection and observation of the mental processes of ourselves and others.

The discovery by Hobbes of the law of association of ideas

Here our study goes back, far before modern knowledge of the brain, to the celebrated English thinker, Hobbes, who first clearly discovered and laid down the law of the "association of ideas", as it is called. We shall see, on consideration, that docility or "educability", the power to learn by experience, does, in fact, mean the power of forming associations in mind and brain, and retaining them. Thinking, from its lowest to its highest forms, is relating —"putting two and two together", forming associations which guide us in the future. The theory of the association of ideas thus constitutes one of the foundations of psychology. First stated by Hobbes, then restated by Locke, and again discussed by John Stuart Mill and many other English psychologists, the association of ideas has given its name to what is often called the "Associationist", or English, school of psychology.

In its simpler forms the association of ideas is obvious, though, indeed, the word "ideas" is rather too limited to use. We associate not merely ideas but all manner of sensory experiences, simple and complex. Thanks to memory, these associations in large degree persist, so that our conduct is modified thereafter.

Association of ideas as seen in the conduct of intelligent animals

We have all observed and commented upon the association of ideas, so called, in intelligent animals. A dog that has been ill-treated by a man in uniform when it was a puppy, hates and fears all men in uniform ever after. This is the essence of associating different facts or learning by experience; and the greatest successes of the human mind depend upon one and the same process. Indeed, if you know what are a man's associations with a random assortment of things, a star, a name, a book, a tune, you begin to know the very man. This is how we are able to judge of one another by our talk, for our talk betrays our associations with whatever topic turns up; and according as one and the same topic suggests different comments and "trains of thought" to different men, so largely can you know those men, their history, their interests and purposes.

We are very liable to think of the association of ideas in purely mechanical terms, as is almost inevitable when we observe how prone we are to form associations between things which merely happen to be seen at the same time, though there is no other relation between them. But this purely mechanical view of the association

of ideas is quite inadequate. Like the whole of our mental processes, which the nineteenth century used to interpret as a kind of "motion picture" succession wherein the mind merely played the part of a passive plate, the association of ideas, from its lowest to its highest, includes a volitional element, due to the vital interests, concerns, intentions, desires, of the individual in question. Otherwise, we should all derive similar associations from similar experiences, and should retain them similarly; nothing could be further from the truth.

The influence of our own wills and interests on association of ideas

The so-called laws of association are no doubt mechanically true in part, but they do not express the whole truth. What you see, and what you associate, mightily depend on what you are looking for. It is not true that the "laws of association" drive us about from pillar to post as if *we* counted for nothing. On the contrary, we each go our own way from similar beginnings, partly because our minds are already stored with different associations, but far more because each of us has his own interests, and thinks accordingly. We wish for something for ourselves, or we hold a belief, in some religion, in money, in evolution, in some scientific theory, in socialism, or what not; and this belief determines the character of our associations and our thinking in general.

How will this affect *me*, or someone I love, or my church, or my belief, or my enemy, or the unborn? These are the questions always asked, respectively, by various kinds of people, according to what they are; and though they all form associations of ideas on similar lines, they use those lines, each in his peculiar way, for his own peculiar ends.

Another criticism to be passed on the purely mechanical theory of association is that it takes too little account of the motive force which drives the chain of associations. Two men may have two very similar brains, may have had very similar experiences, but when you place them in similar circumstances, and expect them both to reach similar conclusions, you are disappointed. The fact is that one of them reaches no conclusions. The chain does not run. If, for some special reason — say, money, or ambition, or self-protection — he were really to be started "thinking on those lines", as we say, he would reach the expected conclusion, but, as a matter of fact, the process stops for lack of motive. The truth is that, as Locke said, the greater part of mankind think very little and very seldom. If they are hungry and notice the smell of food, they think of dinner; and throughout the day they achieve various similar associations but little more. Beyond a certain humble stage, in which many animals may share, as in the case of dinner, we really require some special interest or motive to keep our association sequences going.

The notion that it is purely mechanical and automatic, so that you put in a certain idea or sensation, and then the "wheels begin to go round", is mythical. Every propagandist knows better. The trouble is to get people to think. The machinery is there, and the appropriate start can be made, but nothing happens, because the living will, the purpose, the *élan vital* of the individual, has not been engaged; and after a stage or two the process simply stops for lack of motive. Undoubtedly there is a mechanical element in thinking, which we cannot unjustly represent in terms of the association of ideas, and in pictures of association fibers connecting eye and ear, and so forth, but we go very far wrong if we suppose that this machine will work without power being put into it. That power is the vital intention of the individual, and it is a *sine qua non*. It may be adventitiously aroused, as when a boy studies a subject for a prize, or a politician advocates and "gets up" a subject of another kind for a prize of another kind, and afterwards they never think of the thing again. Or it may be *organic*, whether sane or mad, unselfish or selfish, trivial or momentous; and then the mind of the individual will work along these lines always, not as the ivory ball rebounds from successive cushions of a billiard-table, but as a man goes from point to point because he means to get somewhere.

This is a very profound question, because it involves our understanding of the different types of minds and of men.

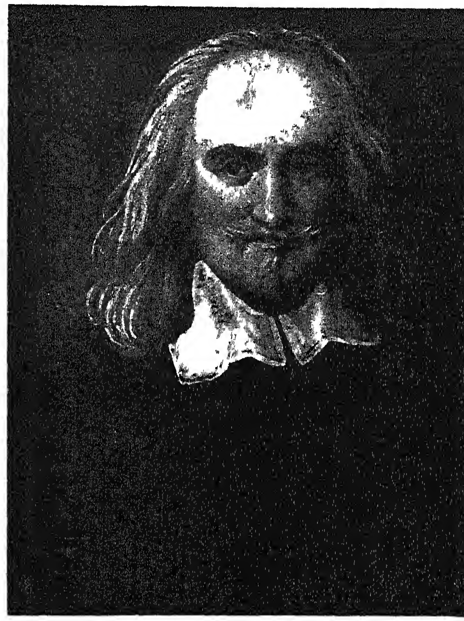
We recognize one man as a "great thinker", and another as nobody in particular. Perhaps we assume that the first man was necessarily more highly endowed with association fibers, and so forth, than the second. He had a different kind of brain, which enabled him to do these feats. In part, of course, this may be true, but it is certainly not the whole truth.

The difference that makes a man a great thinker not usually one of brain structure

Examine the work of one of these great thinkers, and you may find that the taking of any given step, the forming of any given association, was not in itself an exceptional feat. Any of us could have done it — if we had "had the mind", in one sense of that phrase. The second of our two men may have been much more richly endowed than the first, he may have had more opportunities, and the "laws of association" should have done the rest. But, in fact, nothing happened. There was no motive; he did not care; other things attracted him. The man we call the great thinker really had no better a machine, *but he chose to use it*. This view, which is in harmony with general experience, consorts with the view of association which we have just laid down. It gives us the truth that character, the vital drive of a man, the direction of himself, is the most important fact about him. Of course, the machinery is important also, but we must no longer try to interpret the man and his processes solely in terms of his machinery.

Motive power, not body, in men as in automobiles, what really counts

In a letter to his cousin Sir Francis Galton, Charles Darwin wrote, on this very question: "I have always maintained that, excepting fools, men did not differ much in intellect, only in zeal and hard work; and I still think this is an *eminently* important difference." We are here discussing the physical and psychical basis of what we call intelligence or the intellect, and Darwin's verdict doubtless stands, in large measure. Exceptions there are, both in the case of certain individuals and in the case of special kinds of intellect, like that associated with mathematics. But the word "zeal", which Darwin uses, counts for far more than difference in intellect, when we compare the greater number of men with one another. Unfortunately, while it is easy to lay down semi-mechanical laws of association, and even to show how the structure of the brain seems to correspond to them, when we come to "zeal", "interest", the motive power which is present in one man, so that he uses his machine, but absent in another, so that he



THOMAS HOBBES

does not, we pass beyond the limits of knowledge and of material evidence altogether.

Meanwhile the laws and conditions of association, for what they are worth, must certainly be studied. If we consider our own minds we recognize at once that they have a sort of acquired structure which depends upon their experience, largely determined by their interests. In virtue of it we think of things together, or in sequence; we have once thought of them, or have perceived them, in some relation, and we can think of them again in the same relation.

An interesting memory test that incidentally illustrates association of idea

Links of some kind—the nature of which we can imagine as we please — have been formed in our minds, and so the "chain of ideas", as we often call it, can be reproduced at will. Anyone can illustrate the association of ideas for himself, and can also discover a very important fact about what we call memory, by simply writing down a string of nouns, fifty or more, in a column, and then reciting them without a flaw, as he certainly could not do if their sequence did not depend upon such links already existing in his mind.

Thus, noun suggests school, school a particular teacher, his name the name of the place he occupied in the field of science, science suggests biology, biology Pasteur, Pasteur France, France the Battle of the Marne, Marne America, and so on as long as you please. But no two people will compose the same sequence, though all start with the idea "noun"; and, on the whole, the character of the sequences to which we incline will depend upon something deeper than the so-called laws of association.

Elaboration of this game the basis of scheme for aiding the memory

It is upon greatly elaborated systems of association of this character that the greatly advertised schemes for assisting the memory are in many cases constructed.

The last great "associationist", the late Professor Bain, of Aberdeen, whose books, such as "The Senses and the Intellect", go back to the 'fifties of the nineteenth century, always maintained that intellectual or philosophic genius depended upon the number, variety, range and fitness of the associations of ideas. But that in turn must largely depend, as we have tried to insist, upon deeper factors of the mind.

The active part played by the mind in forming associations

Dr. McDougall not long ago wrote confirming the newer view of association which the associationists, from Hobbes to Bain, ignored.

Here is his comment on this: "Thus if I have on one occasion seen a cat seated on the back of a pony, I shall be apt to think of that cat whenever I again think of that pony. The static method describes the fact by saying that the idea of the pony is associated with the idea of the cat, and that the one idea, therefore, reproduces or tends to reproduce the other. . . . The most important point to note is that the mind does not play a passive part in the formation of associations. Objects become associated for the mind, not merely because they are presented to the senses simultaneously or in immediate succession, but when and because the mind perceives or otherwise thinks of them as related with one another; and it does this only in so far as it is interested in them as so related, that is to say, in so far as they stir up some conative [willing] tendency. To go back to the instance of the pony and the cat: if, at the moment my glance fell on the two animals, the cat had been seated on the ground at some little distance from the pony, I should have noticed both animals only in the most fleeting fashion, if at all, and I should not have associated them together. But this spatial relation implied a friendliness between them which is unusual, and appeals to my interest in the behavior of animals; hence, out of all the details of the scene presented to my vision, my mind seizes upon these two animals.

Contiguity and similarity as the two modes of mechanical association

"It may be remarked in passing that this example illustrates the impossibility of describing even so simple a process of association as this in terms of sensation and imagery. The mere spatial relation of the two visual forms is of no interest. It is only because they mean for me far more than is actually presented to the eye that the situation appeals to an interest, and draws my attention."

Given that we realize and accept this truer and deeper view of the association of ideas, there is no harm in our noting the quasi-mechanical laws upon which past psychologists have spent so much study.

It used to be said that association of ideas acts in four ways — by contiguity, simultaneity, similarity and contrast. This fourfold classification may certainly be simplified. Contiguity in space, as, for instance, when an old tune recalls the surroundings in which it was first heard, and simultaneity or contiguity in time, as when the memory of one occurrence arouses the memory of another that happened on the same day, or during the same holiday — these two are both reducible to the single principle of contiguity, either in space or time. Likewise, similarity and contrast, the one being merely the negation of the other, are reducible to one principle; so that the modes of association are really reduced to two — contiguity and similarity.

The rich variety of the mind in forming associations

But these laws or modes of association may work upon all manner of levels. For instance, in conversation a man uses a word which stirs associations in both of his hearers; but whereas in one the association is rational and subtle, beyond psychology to define in mechanical terms, in the other the association is purely sensory and auditory, and leads to the making of a poor pun. The word has suggested another word of similar sound, but no association in meaning. Similarly, in popular catch-words, "king and country", "fifty-four-forty or fight", there is an associative element which is purely sensory, and depends upon a similarity of consonantal sound. The virtue of alliteration or "head-rhyme" is thus explained.

The higher levels of poetry no less susceptible to the laws of association

But the same is true in poetry, and end-rhyme; and every critic soon learns to detect and appraise the level of association on which the poet's mind was moving. Love, dove; pearl, girl; moon, June; star, afar; ocean, motion — these all require careful observation on the part of the critic, in order to decide how far the merely sensory element in association, as against the rational and imaginative elements, has determined the poet's pen. Everyone who is familiar with the poetry of, say, Longfellow and Walt Whitman knows the difference. The two poets each have their definite associative tendencies, certain words and ideas occur, and we may be fairly sure to what they will lead in an ensuing line, but the plane of association is very different in the two cases.

The way in which a clever man can deliberately play with his "faculty" of association, on all sorts of planes at once, is illustrated in much humorous verse, like that of Walt Mason or Lewis Carroll. The latter could at will associate ideas rationally, as in his mathematical treatises, or with a mixture of reason and unreason and mere attention to similarity in sound, as in his delightful "Alice in Wonderland" and "Through the Looking Glass".

The tendency of associations to become fixed and sacrosanct

The element of association in language is well illustrated in onomatopœic words — in which, that is, the name makes the sound named. The Greeks, who coined the term, were great users of onomatopœia, as familiar quotations will recall. Such words are hush, hum, buzz, whirr, whisper, tinkle, rustle, cuckoo, and a host besides, in all languages.

Here there is a perfectly rational association. In other instances, the association between the word and the thing is purely arbitrary. But it is constant, and after a time it comes to wear the aspect of being rational and inevitable, the mind supporting the association between sound and sense to be inherent in the nature of things, as in the case of the old ball player who was asked why a left-handed pitcher is called a "south-paw", and replied: "Why, what else could you call him?"

Early and long-repeated associations tend to become sacrosanct, natural, part of the eternal order of things in this fashion, and when they are broken we are shocked or bewildered beyond measure — as, for instance, at proposals for rational spelling, or at the suggestion to modify a religious ceremonial, which wears for many the aspect of an attack upon religion.

The high importance of the relation between association and memory

Thus we carefully observe that, though all thinking is relationing, or the association of ideas, and though the "laws of association" appear to be general and simple enough, yet there are all levels upon which they work, from that of the old lady who thanked the preacher for the reiteration in his sermon of "that blessed word Mesopotamia", up to the mind of Newton, which leaped from a falling apple to a falling moon.

The association of ideas cannot be left without reference to its high importance in relation to memory. Here we speak, of course, not of sheer memory, which is retention pure and simple, but of the reproduction, the accessibility, of what is retained. It is argued by many psychologists that the purely retention-factor in memory is unmodifiable in each individual, by any means. It appears gradually to decline with advancing years, and is never keener than in the "teens". But far more important is the power to use and to connect what one knows. This depends upon association. The great thing is to have as many hooks as possible with which one can fish up a fact or an idea, or any other memory, from the depths of the subconscious mind. This is achieved by thinking over what one learns, for thinking is associating, relating, and means that new connections are being formed with the memory in question, in virtue of which it will become proportionately more accessible and available in the future.

Associations that resound most curiously through the senses and link them up

A word may be added regarding what is called the "association of sensations". This is a psychological abnormality, though not to be called morbid. Its subject hears trombones, perhaps, and has an associated sensation of crimson. Certain vowel sounds may have definite color-sensations associated with them. Cases are recorded where colors evoke sensations of hearing, where hallucinations of smell and of taste are aroused by color and sound, and *vice versâ*, but by far the commonest are those of visual sensation aroused by sound.

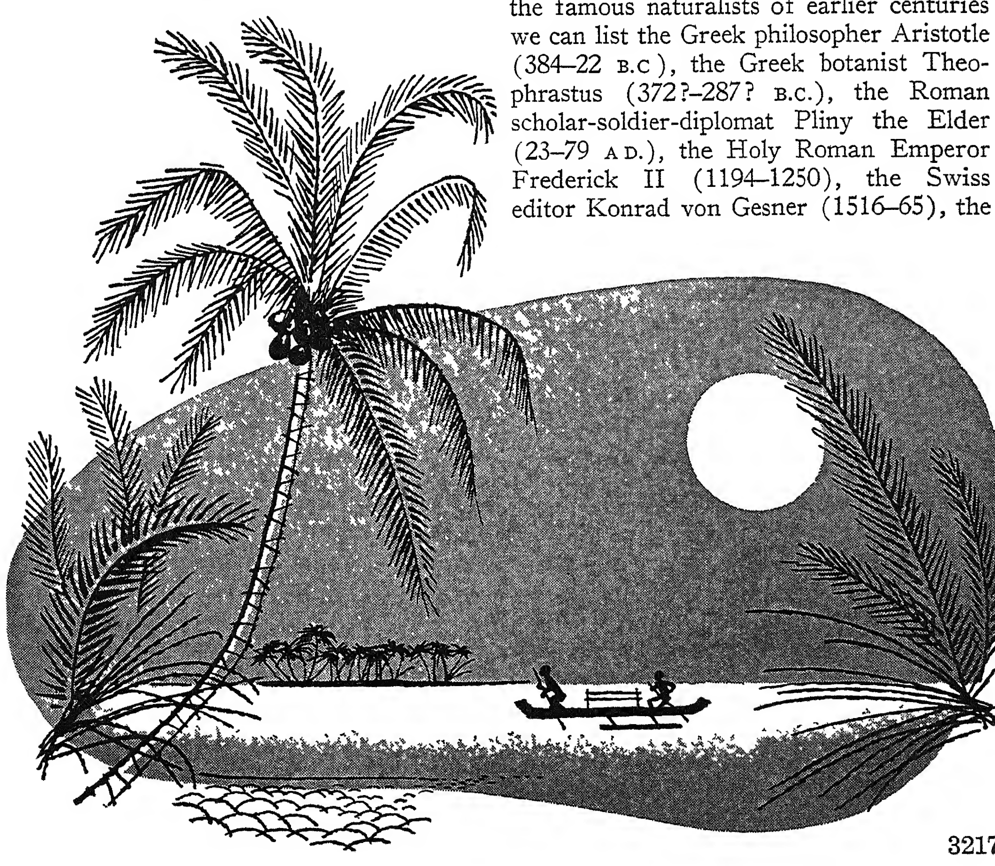
It is probable that such musicians as Wagner, and doubtless many poets — "I *see* the crimson blaring of their shawms" — have been the subjects of association of sensations, but the most numerous instances are recorded among the insane. The cases are striking, because they correspond so well to Hume's theory of the physical mechanism of association — that when any given nerve cell is excited an impulse passes along the nerve fibers which connect that nerve cell with some other, and causes it to yield up its idea, as a bell yields up its note when it is struck. Thus the visual cells are aroused by impulses from auditory cells in action, and yield their specific psychical function, which is vision, according to the law of Müller. Of course, such a theory is hopelessly inadequate when we come to deal with the association of real ideas, but it seems to explain these cases of the association of sensations fairly well.

Science and Progress (1815-95) VIII

by JUSTUS SCHIFFERES

STUDENTS OF THE WORLD'S FAUNA AND FLORA

FROM time immemorial man has been compelled to take an interest in the flora and fauna — the plants and animals — that share the earth with him. Some are his food; others, his enemies. As hunter, herder and farmer, he has been forced to understand their ways. Primitive and savage tribes must and do have a practical working knowledge of some of the subject matter that we should place in the category of botany, agronomy or animal husbandry.



However, as we have observed in earlier chapters of THE BOOK OF POPULAR SCIENCE, almost from the first days of recorded history some men have taken a more comprehensive and scientific viewpoint toward the fauna and flora of the globe. Remembering that science itself was once called "natural philosophy," we designate as naturalists the men who accurately observe and describe plants and animals in their natural habitats. Among the famous naturalists of earlier centuries we can list the Greek philosopher Aristotle (384–22 B.C.), the Greek botanist Theophrastus (372?–287? B.C.), the Roman scholar-soldier-diplomat Pliny the Elder (23–79 A.D.), the Holy Roman Emperor Frederick II (1194–1250), the Swiss editor Konrad von Gesner (1516–65), the

Dutch microscopist Anton van Leeuwenhoek (1632–1723), the French physicist René-Antoine Ferchault de Réaumur (1683–1757), the Swedish botanist Carolus Linnaeus (1707–78), the English clergyman the Reverend Gilbert White (1720–93), an American president — Thomas Jefferson (1743–1826) — and a horde of others.

The nineteenth century had its full quota of naturalists, who added immeasurably to man's knowledge of nature. Some of them roamed far and wide to seek out the mysteries of plant and animal life. For the first time the sharp distinctions between species in different areas of the world was brought vividly to the attention of scientists.

The romantic islands of the South Pacific attracted numbers of eager scientific adventurers. Brawny, cheerful Joseph Dalton Hooker (1817–1911), English botanist and physician, served as assistant surgeon on Sir James Ross's expedition to the Antarctic regions; he studied the flora of New Zealand and Tasmania and of the Far South, too. Thomas Henry Huxley (1825–95), staunch ally of Charles Darwin, was a surgeon on H.M.S. Rattlesnake, which did surveying work in Torres Strait, between New Guinea and Australia. Huxley studied the surface life of the South Pacific Ocean; among other things, he made some important discoveries concerning the family of the Medusae. The naturalist Alfred Russel Wallace (1823–1913) spent eight years (1854–62) in the Malay Archipelago. Here he collected the materials for his absorbing narrative THE MALAY ARCHIPELAGO, which appeared in 1869, and he built up the vast insect collection that passed, after his death, to the University of Oxford and the British Museum.

The notable contributions of Von Humboldt to the knowledge of the fauna and flora of South America were discussed in an earlier chapter. His traveling companion, the French naturalist Aimé-Jacques-Alexandre Bonpland (1773–1858) discovered many new species of plants on the South American continent and Mexico. Charles Darwin, whom we shall discuss later, also did a vast amount of observing and collecting in South America while serving as a naturalist on H.M.S. Beagle. Alfred Russel Wallace joined forces with Henry W. Bates (1825–92) in a collecting expedition in the Amazon Basin. Bates carried on after Wallace's departure in 1850; in 1859 he returned to England with eight thousand hitherto unknown species of insects.

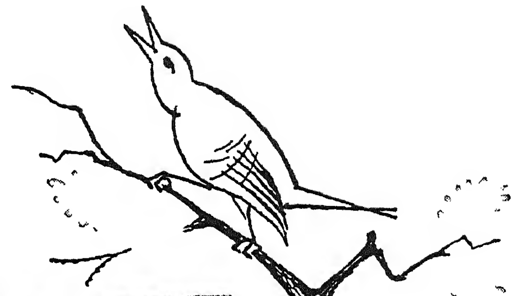
Some of our most fascinating pictures of South America — its birds of many colors, its lush foliage, its sprawling plains (pampas), its lofty mountains — have come from the inspired pen of William Henry Hudson (1841–1922). Born in Argentina of American parents, he wandered about Argentina and Uruguay in his youth, studying the wildlife of these regions. He had chosen to be, so he said, "a naturalist in the old, original sense of the word, one who is mainly concerned with the 'life and conversation of animals.'" Later he settled in England where he became a prolific writer. His ARGENTINE ORNITHOLOGY, written in collaboration with P. L. Sclater and published in 1888–89, is an admirable work on bird lore. Hudson's best-known work, perhaps, is GREEN MANSIONS (1904), a novel whose scene is laid in a forest of South America.

North America also attracted many a roving naturalist. Rafinesque and Audubon, both of foreign birth, were misunderstood pioneers of scientific curiosity in America's backwoods. Constantine Samuel Rafinesque (1783–1840), born in Constantinople (now Istanbul) of French parents, settled in the United States in 1815 and traveled throughout his adopted country on collecting trips. He described many new species of plants, including a number that were medically useful; he also discovered many new species of fishes, particularly in the Ohio River and its tributaries.

John James Audubon (1785–1851) was probably born in Haiti, and was the son of a retired French naval officer. He was educated in France, studying drawing for some time under the great French painter Jacques-Louis David. In

1803 he came to America in order to take possession of a farm owned by his father not far from Philadelphia. After marrying, he tried to settle down as a small businessman in Ohio and Kentucky but failed miserably; to make a living he was forced to paint portraits and to teach dancing and fencing.

From his boyhood, he had spent much time in sketching birds and studying their habits. He now took up seriously the task of watching and painting birds in their natural habitats. He traveled through the wilderness and up and down the Missis-



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John James Audubon, great American naturalist; two drawings from his *Birds of America*.

sippi River, plying his brush. In 1826 he took his sketches to England, where he worked them up into the great collection of hand-colored plates that won him fame and fortune — THE BIRDS OF AMERICA (1827–38) These plates, with descriptive material supplied by William McGillivray, also appeared in Audubon's ORNITHOLOGICAL BIOGRAPHY (1831–39). He was collecting material for a similar work on AMERICAN QUADRUPEDS when he died; this work was completed after his death by his two sons. Audubon was one of the earliest American conservationists. His name is perpetuated in the famous National Audubon Society, which seeks to protect the birds and other wildlife of America.

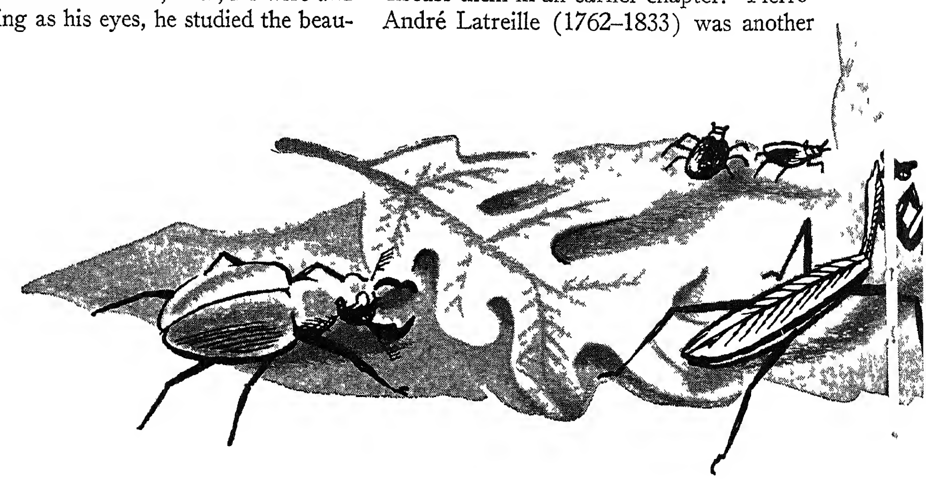
The catalogue of later North American naturalists is a long one. It includes John Burroughs (1837–1921), a New Englander who loved song sparrows, bluebirds and juncoes; Scottish-born John Muir (1838–1914), who grew up to love the woods of Wisconsin and the mountains of California; English-born Ernest Thompson Seton (1860–1946), who lived in the backwoods of Canada and the western plains of the United States and who wrote animal tales and travel stories; and Donald Culross Peattie (born in 1898), who combines a profound knowledge of nature with a delightful style.

Switzerland has produced a number of brilliant naturalists. Prominent among them is gallant François Huber (1750–1831). He began to lose his sight at fifteen and later became totally blind. With his faithful servant and, later, his wife and son acting as his eyes, he studied the beautifully complicated life of the bee. He was the first to observe the mating flight of the queen bee, the killing of the drones by the workers, the ventilating system of the beehive and a thousand other intimate details of the community life of the bee.

Augustin-Pyrame de Candolle (1778–1841) was born in Geneva, became famous in Paris and later returned to his native land to become professor of natural history at Geneva. He set forth the first complete natural system of classification for the vegetable kingdom. His work of classification was carried forward by his son Alphonse-Louis-Pierre-Pyrame (1806–93), and by his grandson Anne-Casimir-Pyrame (1836–1925).

The Forel family of Switzerland is also important in the annals of natural history. Auguste-Henri Forel (1848–1931) is chiefly known, perhaps, as a psychiatrist and a pioneer in sex hygiene. But he was also a first-rate entomologist (authority on insects). He was particularly interested in the psychology of ants; his book called THE PSYCHIC CAPABILITIES OF ANTS AND OTHER INSECTS (1901–04) is a classic in the field. His cousin François-Alphonse Forel (1841–1912) was a physician whose real interests lay in natural history and geology. He studied the freshwater creatures of Lake Geneva and Lake Constance, as well as the glaciers of the Alps.

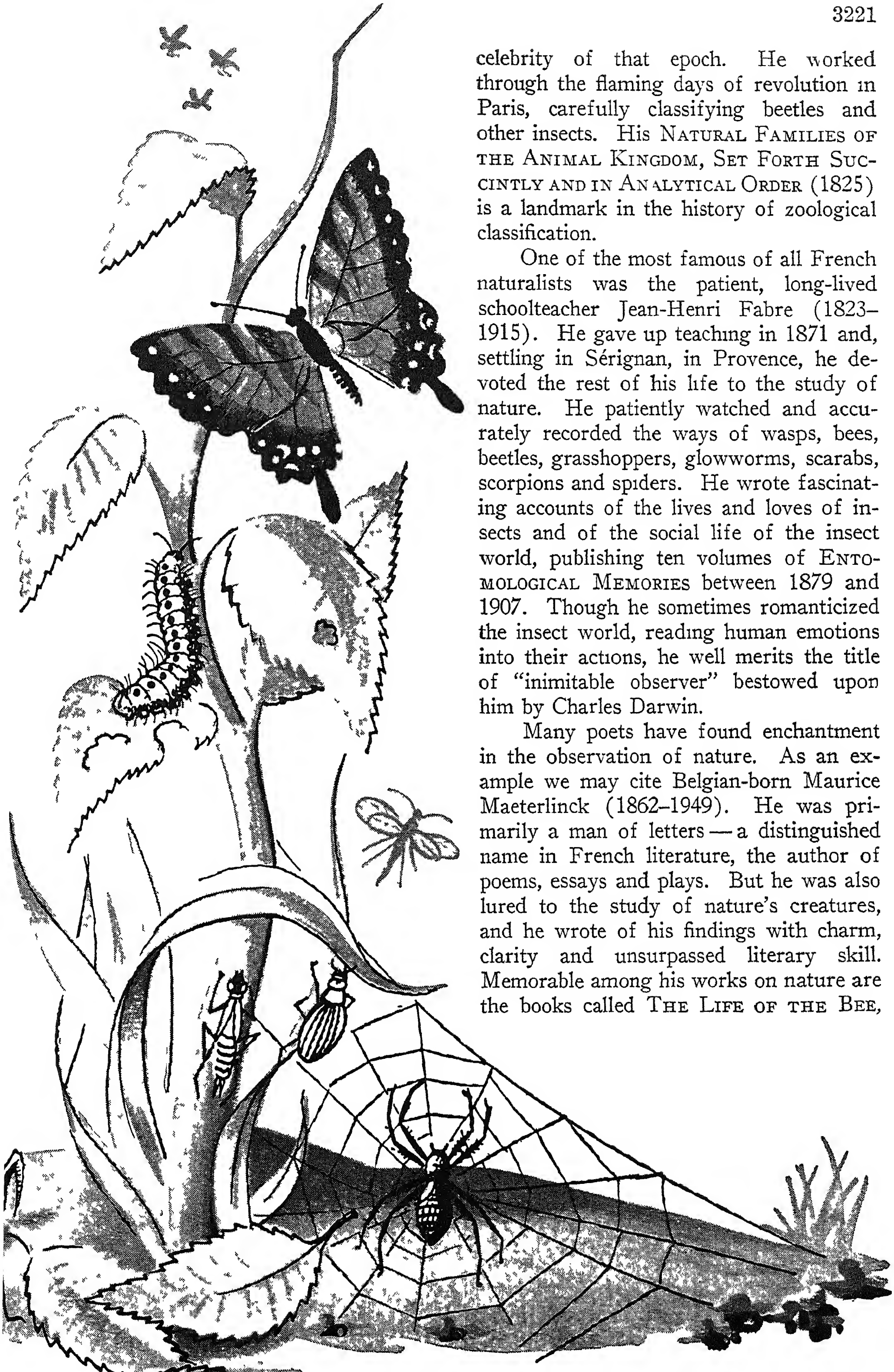
In France, Cuvier and Lamarck were the great names in natural history in the early years of the nineteenth century; we discuss them in an earlier chapter. Pierre-André Latreille (1762–1833) was another



celebrity of that epoch. He worked through the flaming days of revolution in Paris, carefully classifying beetles and other insects. His Natural Families of the Animal Kingdom, Set Forth Succinctly and in Analytical Order (1825) is a landmark in the history of zoological classification.

One of the most famous of all French naturalists was the patient, long-lived schoolteacher Jean-Henri Fabre (1823–1915). He gave up teaching in 1871 and, settling in Sérignan, in Provence, he devoted the rest of his life to the study of nature. He patiently watched and accurately recorded the ways of wasps, bees, beetles, grasshoppers, glowworms, scarabs, scorpions and spiders. He wrote fascinating accounts of the lives and loves of insects and of the social life of the insect world, publishing ten volumes of Entomological Memories between 1879 and 1907. Though he sometimes romanticized the insect world, reading human emotions into their actions, he well merits the title of "inimitable observer" bestowed upon him by Charles Darwin.

Many poets have found enchantment in the observation of nature. As an example we may cite Belgian-born Maurice Maeterlinck (1862–1949). He was primarily a man of letters — a distinguished name in French literature, the author of poems, essays and plays. But he was also lured to the study of nature's creatures, and he wrote of his findings with charm, clarity and unsurpassed literary skill. Memorable among his works on nature are the books called The Life of the Bee,



THE LIFE OF THE WHITE ANT and PIGEONS AND SPIDERS, among others.

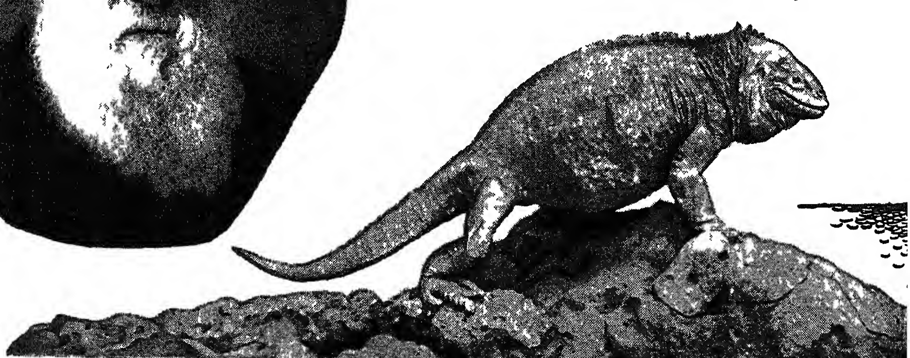
Generally speaking, the naturalists of the world do not create much stir. They go their own way, content to "open a few windows upon the world that is unexplored," to quote Fabre. In the nineteenth century, however, a patient English naturalist, pondering over the data that he and others had collected, developed a theory that was to set the world by the ears. In the following pages we shall discuss this naturalist — Charles Darwin — and his theory of organic evolution.

THE BOMBSHELL — EVOLUTION

In the year 1860, the British Association for the Advancement of Science was holding its annual meeting in the cloistered halls of Oxford University. On the third day of the meeting, June 30, there was to be a debate on a revolutionary book published by Charles Darwin the year before. This work, entitled THE ORIGIN OF SPECIES BY NATURAL SELECTION, maintained that all species of living things had reached their present state through a process of evolution. Among the debaters was to be the Reverend Samuel Wilberforce, Bishop of Oxford and a sworn foe of the evolutionary theory, and the biologist Thomas Henry Huxley, one of Darwin's most ardent supporters.

After some preliminary skirmishing the Bishop of Oxford rose heavily to his feet and launched into an impassioned attack on Darwin's theory. Toward the end of his speech, he turned to Huxley and said smilingly, "I should like to ask Professor Huxley, who is sitting by me and is about to tear me to pieces when I have sat down, as to his belief in being descended from an ape. Is it on his grandfather's or his grandmother's side that the ancestry comes in?"

The good Bishop evidently was under the impression, as so many people have been from that time to this, that the central idea of the ORIGIN OF SPECIES is that man is descended from the apes. Actually, the doctrine of organic evolution, as expounded in the ORIGIN OF SPECIES and in other works of Darwin, stresses particularly the idea that all living things — men, monkeys, amoebas, starfish, birds and plants, for example — have attained their present structure and function through a slow eon-long series of changes in living tissue, beginning with the simplest "primordial protoplasm." The doctrine states further that the direction of changes is guided (though not necessarily altogether) by the process known



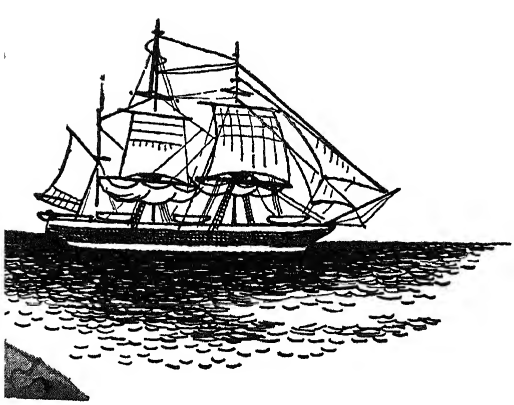
Left: Charles Darwin. Below: giant iguana, found in the Galapagos Islands.

George Stone, from Ewing Galloway

either as natural selection or the survival of the fittest. This doctrine of organic evolution, greatly modified since it was first presented, has profoundly influenced the thinking of mankind.

The author of THE ORIGIN OF SPECIES — Charles Darwin — was a mild, modest and persevering gentleman, whose personal life was not nearly so exciting as his ideas. He was born at Shrewsbury, England, in 1809, the grandson of the physician-poet Erasmus Darwin (of whom more later) and the famous potter Josiah Wedgwood. Darwin received his higher education first at the University of Edinburgh, where he had the idea of working for a medical degree, and later at Christ's College, Cambridge, where he planned to study for the ministry.

The turning point in his career came in 1831 when he signed on H.M.S. Beagle to serve without pay as a naturalist. (We described the Beagle expedition in a previous chapter.) For five years Darwin roamed the seven seas; he carefully noted the fauna, flora and geology of many little-known lands. The Galapagos Archipelago, off the western coast of South America, gave him most food for thought. On almost every one of the tiny islands making up the archipelago, he discovered different kinds of living creatures — species unknown to science. That, among other things, set him thinking about the origin of all species — "that mystery of mysteries," as he called it. Upon his return to England, the young naturalist became the secretary of the Geological Society. In 1839 he married his cousin Emma Wedgwood; three years later the young couple moved to Downe House, near the village of Downe, in Kent. Here Darwin lived the rest of his life.



In 1837 he had begun to collect facts about the formation of different breeds of domestic animals and plants. He observed in his notebook that selection was the keystone of man's success in bringing about variation in different breeds. "But," he added, "how selection could be applied to organisms living in a state of nature remained for some time a mystery to me." The clue to the solution of this mystery was offered to him by the ESSAY ON THE PRINCIPLE OF POPULATION, by Thomas Robert Malthus (see page 1675).

"In October, 1838," he observes, "I happened to read for amusement Malthus on Population, and being well prepared to appreciate the struggle for existence which everywhere goes on from long continued observation of the habits of animals and plants, it at once struck me that under these circumstances favorable variations would tend to be preserved and unfavorable ones to be destroyed. The result of this would be the formation of a new species. Here then I had a theory by which to work."

Darwin now set about to put this theory to the test. Some of the data that he used came from the breeding of domestic animals and birds. (He himself was a pigeon fancier.) He also studied the "record in the rocks" — the geological story and the regular sequence of fossils; "the story in the egg" — the evidence of unfolding layers in the growing organism; the classification of animals and plants according to their characteristics and their geographical distribution. The Darwin and Wedgwood family fortunes made it possible for the young naturalist to devote himself exclusively to his studies. He did not let himself be turned from his self-imposed task by the severe headaches that tortured him with increasing frequency. As the years went on, his views gradually

crystallized and a reasonably complete theory of organic evolution emerged in his mind. It was one of the most revolutionary generalizations in the history of science.

The central idea of evolution goes back to antiquity. The ancient Greek philosopher Aristotle, as we noted in our discussion of ancient science, classified living things according to the amount of soul stuff they possessed. He set up a "ladder of nature," in which man is represented as the highest point of one long and continuous ascent from the very lowest forms to be found in nature. The seventeenth-century German philosopher Leibniz pointed out that the different classes of animals are so connected by in-between forms that it is practically impossible to determine where a class begins or ends.

In the eighteenth century, the French naturalist Buffon (see pages 1223-25) had pointed out the close similarities between kindred species such as the wolf and the dog and implied that one species may have developed from the other. He believed that environment has a direct influence on the development of species. "How many species," he wrote, "being perfected or degenerated by the great changes in land and sea, by the favors or disfavors of nature, by food, by the prolonged influence of climate, are no longer what they formerly were?"

Erasmus Darwin (1731–1802), the grandfather of Charles, was greatly influenced by Buffon's views. In his treatise called ZOONOMIA, OR THE LAWS OF ORGANIC NATURE, he introduced certain evolutionary doctrines of his own. He was impressed by the natural changes produced in animals after their birth (thus the caterpillar gives rise to the butterfly); the changes produced by man (as in the case of dogs bred for strength, courage, acuteness of smell or swiftness); the changes produced by climate (as in the case of hares whose fur becomes white in the winter).

He held that all organisms are ultimately derived from one and the same kind of "living filament," and that species are transformed one into the other. "All animals," he said, "undergo transformations which are in part produced by their own exertions . . . and many of these acquired forms or propensities are transmitted to posterity." This statement is only partly true. Animals undergo transformations, but acquired characteristics are not transmitted.

The French naturalist Lamarck (see Index) gave his views on evolution in his ZOOLOGICAL PHILOSOPHY (1809). He thought of nature as a creative force continually fashioning living creatures, which he arranged in a broad "staircase" leading upward to the higher apes and man. He held that changes in species had come about in order to meet the challenge of the environment. The giraffe, he argued, got its long neck because it reached for leaves on high trees; moles lost their eyes because they had lived underground for several generations. Lamarck also held (wrongly) that the new characteristics that one generation of animals acquired is passed on directly to the following generation.

Charles Darwin's views on the transformation of species

We have mentioned above only a few important names in this brief account of the predecessors of Darwin. The number of naturalists and others who had referred, more or less vaguely, to the idea of the transformation of species is legion. But Darwin was the first to bolster theory by abundant data. Furthermore, nobody had anticipated the central idea of THE ORIGIN OF SPECIES — that new species may arise as a result of the action of external conditions on variations from a specific type. This concept was, as Huxley pointed out, "as wholly unknown to the historian of scientific ideas as it was to biological specialists before 1858."

A thorough, painstaking man, Darwin would probably not have presented his ideas to the world as soon as he did had it not been for an unusual circumstance. On June 18, 1858, he received a manuscript in the mail from the naturalist Alfred Russel Wallace, who was at that time in the Malay

ALFRED RUSSEL WALLACE

Archipelago. Wallace asked Darwin to give him his opinion of the manuscript, which he was to forward to the famous geologist Sir Charles Lyell.

To Darwin's dismay, his own theory, formulated many years earlier, was set forth in Wallace's manuscript. He sat down that very day and wrote to Lyell about this amazing development. "I never saw a more striking coincidence," he wrote. "If Wallace had my manuscript sketch written out in 1842, he could not have made a better short abstract. Even his terms now stand as heads of my chapters."

At the suggestion of Lyell and the botanist Hooker, Darwin sent Wallace's essay to the Linnaean Society, together with an abstract of his own theory. These two essays were read to the Linnaean Society on July 1, 1858, as a joint paper, called On the Tendency of Species to Form Varieties and on the Perpetuation of Varieties and Species by Natural Means of Selection.

Darwin now realized that it was high time to present his theory in its more or less complete form to the general public; and so, on November 24, 1859, he published ON THE ORIGIN OF SPECIES BY MEANS OF NATURAL SELECTION. This work was, next to Newton's PRINCIPIA, perhaps the most important single book in the history of science. Perhaps the best way to give you some idea of its content is to set down what the author himself says in his introduction.

"In considering the origin of species," he writes, "it is quite conceivable that a naturalist . . . might come to the conclusion that species had not been independently created but had descended, like varieties, from other species . . . Naturalists continually refer to external conditions, such as climate, food et cetera, as the only possible cause of variation . . . But it is preposterous to attribute to mere external conditions the structure, for instance, of the woodpecker with its feet, tail, beak and tongue so admirably adapted to catch insects under the bark of trees.

"It is, therefore, of the highest importance to gain a clear insight into the means of modification and co-adaptation. At the commencement of my observations it seemed to me probable that a careful study of domesticated animals and of cultivated plants would offer the best chance of making out this obscure problem. Nor have I been disappointed.

"We shall thus see that a large amount of hereditary modification is at least possible. What is equally or more important, we shall see how great is the power of man in accumulating by his selection successive slight variations. I will then pass on to the variability of species in a state of nature.

The struggle for existence among all organic beings

"We shall be enabled to discuss what circumstances are most favorable to variation. Next the struggle for existence among all organic beings throughout the world, which inevitably follows from the high geometrical ratio of their increase, will be considered. This is the doctrine of Malthus . . .

"As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form.

"We shall see how natural selection almost inevitably causes much extinction of the less improved forms of life, and leads to what I have called divergence of character . . . I am fully convinced that species are not immutable . . . [and] that natural selection has been the most important, but not the exclusive, means of modification.

"We shall best understand the probable course of natural selection by taking the . . . [imaginary] case of a wolf, which preys on various animals, securing some by craft, some by strength and some by fleetness. Let us suppose that the fleetest prey, a deer for instance, had from any change in the country increased in numbers, during that season of the year when the wolf was hardest pressed for food. Under such circumstances the swiftest and slimmest deer would have the best chance of surviving and so, of being preserved or selected.

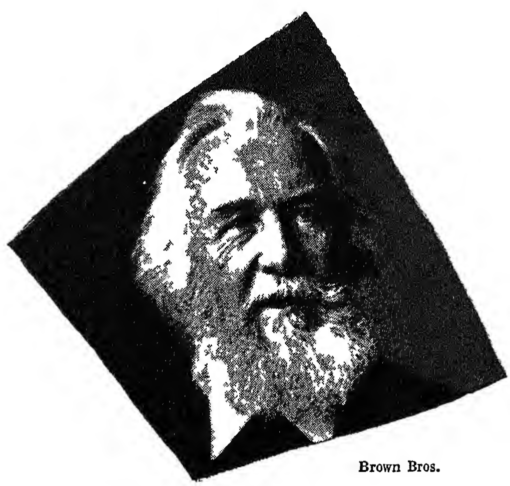
Natural selection, or the survival of the fittest

"This principle of preservation, or the survival of the fittest, I have called natural selection. It leads to the improvement of each creature in relation to its organic and inorganic conditions of life; and consequently, in most cases, to what must be regarded as an advance in organization. Nevertheless, low and simple forms will long endure if well fitted for their simple conditions of life."

In the course of the years that followed, Darwin made other notable contributions to his theory of organic evolution — particularly THE VARIATION OF ANIMALS AND PLANTS UNDER DOMESTICATION (1868), THE DESCENT OF MAN (1871) and THE EXPRESSION OF THE EMOTIONS (1872). He died on April 19, 1882; and seven days later he was buried in Westminster Abbey, where lie many of England's most famous sons.

The most effective tribute, perhaps, to the man and his work was paid by Alfred Russel Wallace, the co-discoverer of the theory of natural selection. He wrote of Darwin in 1870: "I have felt all my life and I still feel the most sincere satisfaction that Mr. Darwin had been at work long before me, and that it was not left for me to write the ORIGIN OF SPECIES . . . Far abler men than myself may confess that they have not that untiring patience in accumulating and that wonderful skill in using large masses of facts of the most varied kind, that wide and accurate physiological knowledge, that acuteness in devising and skill in carrying out experiments, and that admirable style of composition, at once clear, persuasive and judicial — qualities which in their harmonious combination mark out Mr. Darwin as the man, perhaps of all men now living, best fitted for the great work he has undertaken and accomplished."

Darwin had remained aloof from the violent controversy aroused by the appearance of the ORIGIN OF SPECIES. The theory of organic evolution had burst like a bombshell upon the England of the late 1850's and early 1860's. The theory was violently attacked by certain clergymen



Brown Bros.

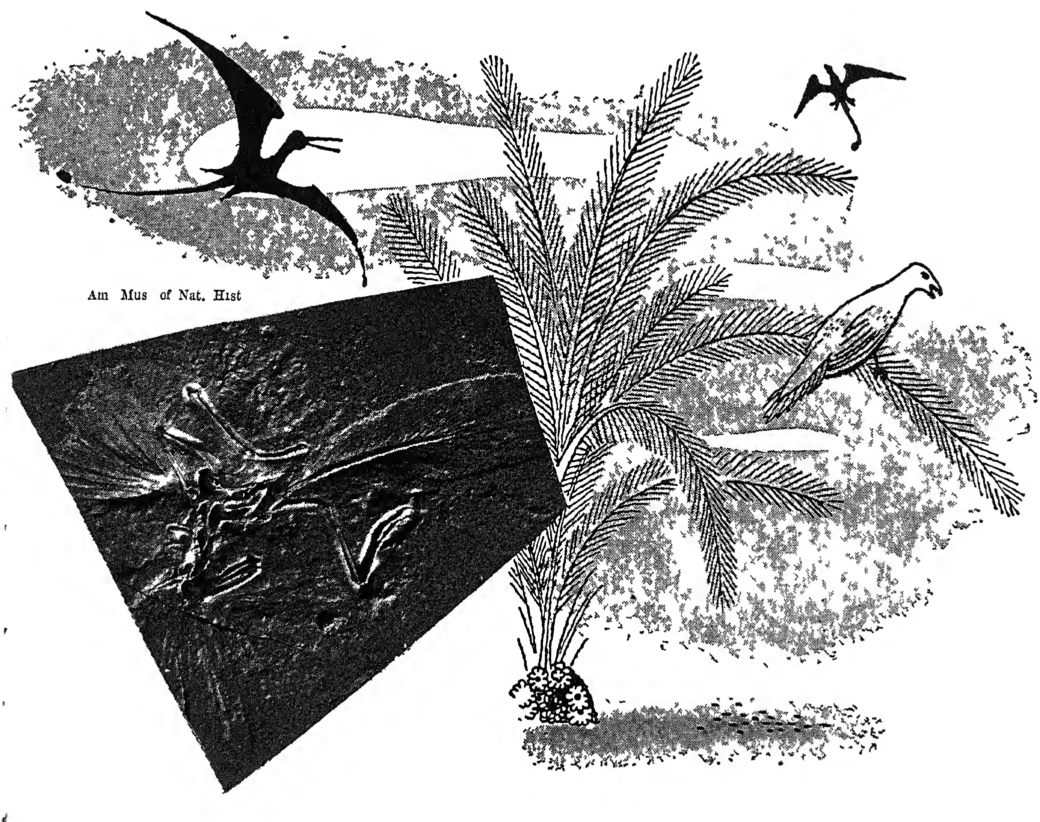
Ernst Heinrich Haeckel, above, drew up a genealogical tree, displaying the different series of living things in a series that ranged from the amoeba to man himself Lopped-off branches represented "missing links" These were sometimes found in fossil forms, such as the archaeopteryx (half bird, half lizard), shown at the right It was found at Solenhofen, in Bavaria

(including, as we have seen, the Bishop of Oxford) as contrary to the teachings of the Bible. Certain scientists, too, including the comparative anatomist Sir Richard Owen and the geologist Adam Sedgwick, objected to Darwin's findings. Other scientists rallied to Darwin's support. his generous rival Wallace, the botanist Hooker and above all the redoubtable Thomas Henry Huxley.

Why did Darwinism create such a furore? One reason was undoubtedly that the ORIGIN OF SPECIES lumped man together with other living things as a product of organic evolution, thus apparently contradicting the Biblical story of creation. The political and social conditions in England at the halfway mark of the nineteenth century also offer some explanation of the heat of the Darwinian controversy in that country.

Politically speaking, the battle over Darwin represented a fight between liberals — for him — and conservatives — against him. England was feeling the full effects of the Industrial Revolution, which was breaking down old forms, old customs, old families, old fortunes. Those who had benefited by the change — first and foremost, the industrialists who were creating new fortunes and who wanted a louder voice in public affairs — were likely to view all changes as beneficial. They saw a new world of iron and steel, of fast transportation and easier communication growing up around them. Hence they thought of change as progress, and they used the word evolution as a synonym for progress. Again, the fierce competition for markets and for business survival impressed men — that is, those who were successful in the competition — with the validity of the doctrine of the survival of the fittest. (They rarely asked the question· "Fittest for what?") Opposed to these apostles of change were those who mourned the passing of the "good old days."

Evolution became something more than a scientific theory, whose significance



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few could truly understand; it became a battle cry and even a philosophy. In England Herbert Spencer (1820–1903) built up an entire philosophical system around the concept of evolution. In 1852 — seven years before the publication of THE ORIGIN OF SPECIES — he had used the word "evolution" to describe the production of higher forms from lower forms. He became an eager disciple of Darwin and fitted the latter's theories into his own philosophy. He saw evolution at work in nature, in the human mind, in human society. He carried the philosophy of evolution into political affairs, too. If nature provides that the fittest shall survive, he reasoned, it follows that the freest are the fittest. Personal liberty became, for him, the highest goal. Governments, he argued, must not interfere with "rugged individualists" or with free enterprise, since these represent natural forces at work.

Germany's political liberals and Darwinism

In Germany *Darwinismus* (Darwinism) became closely tied up with the political liberals or radicals of the 1860's and 1870's. Among the scientific radicals was Ernst Heinrich Haeckel (1834–1919), biologist and philosopher. He was the leader of scientific expeditions to the Canary Islands, the Red Sea, Ceylon and Java; from 1865 to 1908 he was the provocative professor of zoology at the University of Jena. He was also the author of many books, including THE RIDDLE OF THE UNIVERSE (1899), in which he dogmatically claimed that he had "solved" the great problems of life and death.

As a young man Haeckel was an enthusiastic and powerful champion of Darwin. He was an important figure in the development of evolutionary theory. For example, he was the first to draw up the now familiar genealogical tree, relating the various orders of living creatures in a series ranging from amoeba to man. Lopped-off branches represent the "missing links." These are sometimes found in fossil forms, like the birds with teeth discovered by O. C. Marsh and E. D. Cope in the Badlands of South Dakota, or the famous archaeopteryx — half bird, half lizard — found preserved in a piece of shale picked up at Solenhofen, in Bavaria.

Haeckel was the first to present the so-called biogenetic law with his jawbreaking statement that "Ontogeny recapitulates phylogeny." This means simply that in the life history of each individual animal (ontogeny) there are repeated, and in the same order, the stages of growth through which the whole species has passed (phylogeny) in its historic evolution. Or, to put the matter still more simply, every individual is a "historic document." The biogenetic law, so tersely stated by Haeckel, was based on the first-hand research of a number of men, including Thomas Henry Huxley, the German geologist Fritz Mueller and the Russian zoologist Aleksandr Onufrievich Kovalevski.

In France, where the influence of Cuvier (see page 1662) was still strong, Darwinism made slow headway at first; in fact, some important French men of science, including the great physiologist Claude Bernard, were never completely won over. However, the evolutionary theory, known in France as transformism, at last prevailed. This led to a renewed interest in the evolutionary ideas of Lamarck; in fact, French Darwinism was strongly tinged with Lamarckism.

Flaws in Darwin's theory of evolution

By the end of the nineteenth century, the evolutionary theory had won wide acceptance. However, even the firmest supporters of the doctrine of organic evolution had to concede that there were glaring inaccuracies and gaps in Darwin's original theory. For one thing, they found flaws in his complicated explanation of the reproduction process in the germ cell. Darwin held (wrongly) that every cell in the body at every stage of the body's growth is represented in the germ cell (sperm or ovum) by a tiny unit called a gemmule. The reproduction power, he thought, really lies with all the body cells, acting through their representatives, the gemmules. The germ

Sir Francis Galton helped to introduce fingerprint identification.

cell itself is important only as a convenient meeting place for the gemmules. Darwin called this theory, appropriately enough, pangenesis ("all-reproduction": that is, reproduction by all the cells).

This arbitrary doctrine has been discarded. Modern scientists now believe that certain paired bodies in the germ cells — microscopically small units called chromosomes — are the true bearers of hereditary characteristics. Among the Darwinians who fought most eagerly for this concept was the German biologist August Weismann (1834–1914), professor at the University of Freiburg from 1866 to 1912. Relying on his amazing powers of intuition rather than on the facts actually known to him, Weismann located the physical basis of inheritance in the chromosomes and insisted on the continuity of the germ plasm.

He maintained that only hereditary characteristics could be transmitted by means of the chromosomes; he denied that characteristics acquired in one generation could be carried over to the next. To prove his point he snipped off the tails of a number of mice at birth; then he raised and bred the little animals. He dealt with their offspring in the same way, and so with many following generations of mice. In all these generations there was not a single case of a mouse born without a tail.

Darwin gave no adequate explanation of the mechanism of heredity and the way in which "spontaneous variations" are carried on from one generation to the next. An Austrian monk, Gregor Johann Mendel (1822–84), was working on this vital problem at the very time that THE ORIGIN OF SPECIES appeared. In 1865 he published a memorable paper called Researches on Hybrid Plants, in which the mechanism of heredity was accurately set forth. But this paper remained unknown to or disregarded by practically all of Mendel's contemporaries; as we shall see, it was not rediscovered until the year 1900.

Though much of Darwin's original theory has been revamped or discarded, its influence upon almost every field of human activity has been very great. History, archaeology and ethnology have undergone

profound changes because of the theory; in these fields, as the Swedish biologist Erik Nordenskjöld has pointed out, "the development from earlier to later stages has been the one clue for research." The influence of the doctrine of organic evolution has been particularly strong upon the old biological sciences — anatomy, physiology, morphology, parasitology, embryology, cytology, genetics and so on. It has brought into being at least two new biological sciences — eugenics and biometry.

Sir Francis Galton, a man of many talents

Versatile Sir Francis Galton (1822–1911) had a great deal to do with the development of these two sciences. Galton, a first cousin of Charles Darwin, was a man of many talents. He was a scientist, linguist, explorer (he sought the source of the Nile), mathematician, meteorologist (he devised the modern weather map), novelist (at the age of eighty!) and the inventor of the ticker tape and the slide whistle.

The name "eugenics" was invented by Galton in 1885; he derived it from the Greek *eugenes:* well-born. According to his own definition, eugenics "is the study of the agencies under special control which may improve or impair the racial qualities of future generations either physically or mentally." He believed that society should seek to increase, by a conscious selective process, the number of individuals possessing desirable hereditary qualities. He admitted that a statesman might consider tolerance highly desirable and pugnacity just as undesirable, while a soldier might take the opposite view. But Galton pointed out that few people would deny that such qualities as health and energy and ability should be fostered.

Galton was one of the pioneers in biometry, the science of statistics applied to biological observation. Beginning with a study of the stud books of basset hounds, Galton deduced a law of ancestral heredity that says, in effect, that the average contribution of each parent to the heredity of his child is one fourth; of each grandparent, one sixteenth; of each great-grandparent, one sixty-fourth and so on.

Galton set up the first anthropometric laboratory for the measurement of the physical characteristics of man. Among other things, he helped introduce the modern method of fingerprint identification used in crime investigation. Some of the measuring machines he devised for the International Exhibition of 1884, in London — like the punching bag and the test-your-grip machines — are still to be found in penny amusement arcades.

The earlier controversies caused by Darwin's theory of evolution eventually petered out. New controversies followed in their wake. Eugenics became a battleground; the issue was nature (heredity) versus nurture (environment) Is heredity or environment more important in the development of an eminent citizen? Or a genius? Or a moron? We now realize that all this is rather pointless; for a child not only inherits his physical and psychic characteristics but also becomes the product of his physical and social environment. Another violent conflict arose between the mechanists and the vitalists. The mechanists held that all the processes of life can be explained on the basis of chemical and physical laws; the vitalists vehemently denied that this is the case. This controversy no longer excites scientists. It seems to have hinged on the interpretation to be given to certain words, rather than on genuine differences of belief.

The vitalists point out that mechanism is simply a point of view. Human beings and other living creatures act like machines only if you choose to describe them that way. Life is a chemical process only if you insist on analyzing all things chemically. But such a view is narrow and cannot explain everything. As a distinguished American chemist, Jerome Alexander, recently put it: "Many if not all the basic material facts of life are understandable on catalytic [chemical] principles . . . but mental and spiritual phenomena which emerge and which are just as real as the material ones are as inscrutable as ever."

SCIENCE THROUGH THE AGES is continued on page 3366.

IN PRAISE OF PLAIN BREAD

An Examination of the Cereals, and a Comparison of their Different Food Values

WHEAT AS THE WORLD'S CHEAPEST FOOD

ABOUT the value of milk as an article of human diet, as we have seen, there can be no doubt, and in the welter of dietetic controversy its importance for good health has been well established. Almost as much may be said for bread, which is indeed "the staff of life".

Considered as foods, milk and bread are exceedingly different, above all because one is an animal and the other a vegetable food. Now, a great argument in favor of vegetable food in general is its extreme cheapness when compared with any kind of flesh, or even with cheese and milk. In round figures, speaking generally, the cost of vegetable nutriment is about one-fourth that of animal. Foremost among vegetable foods are the fruits or seeds of certain grasses called "cereals". Astonishing, indeed, is the dependence of mankind as a whole upon grass. Now, the most important of all the grasses is wheat, at any rate as far as Western civilization is concerned, and this we usually consume in an elaborately prepared form as bread.

The question of cost is worth close attention. It directly affects every individual, and it is a national matter also, for to discover and obtain the best and cheapest food supply for a nation is a task of the highest kind. But these questions of the cost of food cannot be decided by the amateur, and, indeed, the expert is apt to be content when his inquiry has by no means gone far enough. At any rate, we shall here ignore mere weight of the food or alleged food under discussion, and shall look only at the weight of the actual nutriment which it contains.

This, however, is not sufficiently precise, for we require to distinguish between the different types of nutriment; and it is fair to look at the proteins alone, these being absolutely necessary for life. But even in terms of proteins, as distinguished from nutriment in general, wheat flour is still the cheapest of all foods; and bread, though much dearer than flour, is still much cheaper than milk, meat or eggs.

It has been suggested that we pay the baker very heavily for his trouble, and that, so far as economy is concerned, it would be well worth while to bake at home as our forefathers — or rather, our foremothers — did, but if we consider the fuel, which at the present time is a large item, and the labor and attention necessary to produce good bread, we may conclude that the baker is not paid too much for his trouble after all. Then again there is the question of quality. A great deal of home-made bread is not good, although few housewives will admit this. They will claim that the same thing is true of baker's bread, which is the case, but the bakers as a whole have greatly improved their methods in the last decade and are using better materials. Although there is still room for improvement, the quality of baker's bread in general will average better than that made in the home.

It cannot be said of bread that it is a perfect food for man. In fact, there is no such thing as a perfect food — that is, a single food that will entirely take the place of an ideal mixed diet — but it should and does occupy a high position in the foods of all civilized nations. Bread

contains an excess, then, of energy-producing food, in proportion to its proteins, from which alone living tissue can be recreated. We need somewhat more fat than the proportion in bread supplies. This is the reason that we make bread puddings with eggs and milk, and eat bread with cheese, or spread it with butter, and it is frequently advocated that in the manufacture of white flour the most nutritious part of the wheat is sacrificed. To retain this, however, means the inclusion of the bran and germ which, according to many investigators, is open to question, as there is considerable difference of opinion about the digestibility of these products. When the germ is added in the natural form it turns rancid during warm weather and, like the bran, attracts insects of various kinds, so that the spoilage of graham and whole-wheat flours runs very high, resulting in a great deal of loss and causing annoyance to all concerned. It is therefore apparent that if any of the wheat coating is included in the flour at the time of milling, it must be subjected to a baking temperature long enough to sterilize it sufficiently to prevent loss from rancidity and render it less attractive to insects, which is impractical under present conditions. It is true that this part of the wheat is considerably higher in protein, the most valuable part of the bread, but exhaustive digestion experiments conducted a number of years ago seemed to indicate clearly that the highly nutritive material contained in the bran and germ was so protected by cellulose that the digestive juices were prevented from acting upon it and as a consequence a very large proportion was entirely lost.

The public, however, has its own ideas on these subjects and shows a decided preference for white bread in spite of the efforts of many writers and scientists to the contrary, and as the baker and miller must depend on the public for their business, they naturally do the best they can to supply the demand. If it was for a whole-wheat flour containing all the bran and germ, both would be glad to supply that; in fact, nearly all bakers now make whole-wheat bread to some extent.

The disadvantage of an excess of moisture in bread

Exactly what color to aim at is a further question, but meanwhile we may note that the moisture of the loaf is not without importance. A little over one-third of an average loaf is water, and, surprised though we may be at the large proportion of water in bread, we should remind ourselves that, even so, it is much less watery than raw meat. We must note further, in relation to the color question, that a brown bread is a moister bread; and the purchaser of a brown loaf is buying such an excess of water that, all told, he gets considerably less protein and less starch for a given cost, even though the brown flour does certainly include some of the valuable parts of the wheat which the white flour omits. This point about the excess of water is unfamiliar to most people, and it entirely upsets the usual assumption. Of course, it does not apply to the choice between the purchase of white or brown *flour*, for those who make their bread at home.

The superiority in all respects of crust over crumb

This water question further leads to the conclusion that the common opinion regarding the crust and crumb of bread is also erroneous. The crust is very much superior on all counts without exception, chiefly because it is so much drier. Only to consume the crumb of a loaf involves very great waste indeed. There are thus more reasons than one why we should make a point of eating our crusts, though the term "dry crust" is used almost as if it were equivalent to "dry husk". The crust is dry because it contains so little water, which is another way of saying that it is in proportion more valuable. Also, it is very good for our teeth, and for our children's teeth. One reason why our teeth decay is that we do not use them, an explanation entirely satisfying to the biologist, who knows that effort is the law of life, and that every organ, tissue or function which has its work done for it inevitably degenerates.

Why the crust of the loaf is more digestible than the crumb

Yet further, the crust of bread is much more digestible than the crumb, chiefly because it requires to be chewed, and is thus thoroughly mixed with saliva, which has all the better chance of doing its work because so little water is present in the first place. This is the sufficient reason why new bread, which is simply wetter bread, is less digestible. In a little while most of the water evaporates, and the task of digesting the bread is then simplified. It must be remembered that bread consists very largely of starch, the digestion of which is begun by the saliva of the mouth, but for which the stomach itself produces no ferment at all. If starchy foods are not properly mixed with saliva they simply get in the way in the stomach, and make no chemical progress until they reach the bowel.

The highly nourishing properties of toast, rusks and crackers

It should be added that cooked bread or toast is more digestible and no less nourishing than ordinary bread, this being still truer of the kind of toast called rusks. Crackers, also, are highly nourishing in proportion to their weight, for they contain very little water, and the constituents added to the flour in making them are themselves valuable. Three pounds of crackers are estimated to contain as much nourishment as five pounds of bread. Needless to say, these observations are all double-barreled. They tell the economist and the emaciated what especially to employ, but they also give the too stout man hints as to what he should avoid.

Until recently, many people believed in graham as against white bread. For the moment we here confine the discussion to these two, not dealing with "germ" breads, or any bread made of cream-colored flour. The principal feature which distinguishes real graham bread from all other is its inclusion of the bran. But the bran mainly consists of cellulose, which the human body does not digest in any appreciable degree, and this indigestible cellulose incloses (and therefore preserves) the other constituents of the bran. Two dogs and a hen between them were found to be unable to deal with bran effectively; and this experiment suffices to explain the fact that there is really no relation between the percentage composition of entire-wheat bread and its nutritive value.

We live not by what we eat, but by what we assimilate. In this case, the cellulose is not only indigestible in itself, but a cause of indigestibility in other things. Thus the protein of graham bread is not absorbed as it should be, and even other foods, such as milk, when taken along with it, have their absorption interfered with.

Some doubts about the arguments for brown and entire-wheat breads

The fact is that the arguments in favor of entire-wheat bread as against white bread were based merely upon chemical composition, and should have had regard to the behavior of the bread in the bowel. The former medical practice of recommending the use of entire wheat bread by growing children and nursing women must therefore be abandoned. If entire wheat bread and entire wheat crackers are now to be regarded as having any special virtue, apart from their pleasantness to many palates, it is that the bran they contain is somewhat of a stimulant to the bowel, so that they may be commended in constipation, in some but not all cases.

Brief reference has already been made to the importance of properly mixing the saliva with the bread one eats. The importance of mastication, upon which all recent dietetic and dental authorities insist, is very marked in the case of bread. It is largely because toast and crackers and stale bread and crusts are dry that they are so useful. The teeth can work upon them, and they soak up the saliva, neither of which statements is true of new bread. Also, in the stomach, crackers are found to be much more digestible than ordinary bread, and stale bread than new bread.

The greater likelihood of a mixed diet giving the body what it wants

As a general rule vegetable foods are much less well absorbed than animal; but on the whole, and compared with other vegetable foods, white bread is extremely well absorbed — best of all when taken with other kinds. Indeed, everything goes to show that not only is man best suited by a mixed diet, but that, at any rate in health, he profits best by a mixture of foods taken at any one time. Much of the salts of bread, including its iron, is unabsorbed; and an increase of the proportion of salt by the use of the bran of the grain is probably merely an increase in what is swallowed, not in what is used. In modern milling the object is to obtain as much flour of good appearance and quality as possible and to diminish the yield of bran and shorts to a minimum. Graham flour is unbolted wheat meal ground from the whole kernel. Whole or entire-wheat flour contains all the kernel except a portion of the bran. The patent and clear grade flours contain the endosperm and very little of the bran, germ and embryo.

We have finally decided in favor of white as against entire-wheat flour. But so-called white flour may and does vary very widely in composition — a fact to which doctors have been drawing attention for many years. Inquiry has been specially directed to the difference between the various grades of white flour, and the opinion has been abundantly confirmed that the higher gluten or protein wheats of the Northwest produce flours of much higher food value than the softer wheats. This type of flour should and does command a premium, not only for its higher nutritive value but its superior bread-making qualities.

Obscure qualities in foods that give them a special value

However, in the course of special study of this question of the kinds of flour, it was shown that what is now often called pure or "hard patent" flour has a superiority which is not to be explained solely in terms of its excess of protein. If some such percentage of superiority were all it could boast, a slight increase in the amount of "patent" consumed would put things right. But that appears not to be the case. The fact is that these strong flours contain a substance, or perhaps a series of substances, which have a specific virtue of their own in relation to nutrition, but which are absent, or nearly absent, from the softer flour. We cannot name or define these substances nor can we allot them to any of the great classes of food-stuffs which we first found exemplified in milk — proteins, carbohydrates, fats and salts. But that merely shows how inadequate our knowledge of dietetics still is.

The fact is that this comparatively recent discovery regarding the wheat-grain is only one of a large number, all of which point in the same direction. The study of milk taught us that there are certain great classes of food-stuffs necessary or very desirable for health. But we also learned that there seem to be some obscure substances in milk that cannot be called foods, on the ordinary physiological definition, but yet are very desirable for health. Some time ago light was thrown on a long-mysterious disease called beri-beri. In India and Ceylon and other parts of the world certain people are suddenly taken with an illness which involves inflammation of the nerves, great weakness of the muscles, painful rigidity of the limbs, and general symptoms of poisoning. It looks as if they had been attacked by something comparable to the arsenic, lead, alcohol, etc., which are known to produce similar symptoms. No such cause could be found. A microbe or other parasite was long hunted for, without success. But now it has been proved convincingly that the symptoms are all due to the lack of something from the diet of the patient. He has been living almost exclusively on rice which has been "polished", the outer skin of the grain having been removed. But that outer skin contains minute traces of a chemical compound without which the disease called beri-beri will appear.

The disease called scurvy, which is now no longer a mystery

A far older instance is that of the disease scurvy, which often attacked sailors when fresh fruit and vegetables became unavailable in the course of long voyages.

Here is a disease from which we are all protected by something that we take in an ordinary diet and that we call vitamin C. It is not a food in the ordinary sense of the word, according to the long-accepted physiological definition which we shall shortly study. When humans are deprived of fresh fruit and vegetables, containing vitamin C, even though they are well fed on proteins and carbohydrates and so forth, they are liable to suffer from scurvy, a disease of nutrition, which has its parallel in the "infantile scurvy" of improperly fed infants. The regular supply of lime juice, rich in vitamin C, is sufficient to prevent the disease.

There was a time when students of nutrition confidently made the assumption that the value of any diet might be determined by making chemical analyses of the proteins, carbohydrates and starches that it contained. They overlooked those essential ingredients, the vitamins. Though we still do not know exactly how the vitamins act, we do realize that they are an absolutely indispensable part of a well-balanced diet. We have already identified a considerable number of vitamins and have determined in what foods they are to be found. You will find more information about this subject in other chapters of our set.

Valuable forms of wheat that are known under other names

This is far too big a subject to be dealt with incidentally here, but we have already seen enough to make us realize that the supposed superiority of bread made from flour which includes much of the germ of the grain may not be as important as many believe, particularly when a mixed diet is available. Wheat is such an invaluable food-stuff that we should be acquainted with the various forms, other than bread and crackers, in which it is presented to us. These include semolina, macaroni, vermicelli, Italian pastes, "shredded wheat", "Force" and "Grape-Nuts". Not every housewife knows that the first three mentioned are really wheat flour, and therefore rank specially high in the dietetic scale. There is an immense interval, for invalids and children and everyone else, between such substances and, for instance, arrowroot, a favorite invalid food of the past, which practically consists of nothing but starch, is scarcely worth eating at any time, and is certainly a mockery for invalids. As for the ready-to-serve preparations, these are all whole-wheat preparations, easily prepared, readily obtained and deliciously flavored.

Some of the relations, rich ones, of that prince of cereal food: wheat

Wheat, we have seen, takes first place among the cereals, but its relatives may conveniently be dealt with here also. Oats, for instance, are a very valuable source of food. Growing as they do in the north, they are somewhat rich in fat, for such a useful source of heat is required for the purposes of a young plant that is to grow in high latitudes. Thus, oats are rich in fat; while rice, which grows in warm climates, is poor in it. Hence, both on account of its fat and because of the irritant and innutritious husk, ordinary oatmeal is not a very suitable food for those whose digestion is delicate. The consumer of ordinary oatmeal porridge who finds his digestion troubling him should give it up. Some of the recent rolled oats, however, are more easily digestible, though the method by which they are prepared somewhat reduces the nutritive percentages in the product. By those whose digestion is good, oatmeal porridge is very well absorbed.

Another excellent cereal, Indian corn, agrees with oats in not containing the glutinous ingredient by which wheat flour can be made into bread; but "johnny cakes", which form an important part of the diet in certain sections, do not compare very well with white bread made from the strong wheats on account of a much lower protein content.

Barley is another important cereal which is of very considerable nutritive value, though it is inferior to wheat. Loaves made half and half of wheat and barley-meal are an excellent article of diet, however. There is no appreciable nourishment in barley-water, which is, nevertheless, an excellent drink in its way.

Last, but not least, in this list of the cereals comes rice, the grass which supplies food for more of mankind than any other; indeed, it is said to be the staple food for one-third of our species.

Though it agrees with the other cereals in general, it is distinctly inferior to them. We have already seen that it is relatively poor in fat, of which the young embryo needs less in a hot climate. But it is also very poor in protein — say about one-third as well provided in this respect as wheat. Indeed, we have to look upon rice as mainly a starchy food, barred, of course, to infancy. This also means that, for a proper diet, rice must be supplemented by other substances, richer in the protein or nitrogenous constituents.

Rice, no doubt, has its virtues, especially when it is understood. It is best cooked by steaming. The Italians, into whose country rice was introduced a few centuries ago, do well to eat it in the form of what they call "risotto", for then they take eggs and cheese with it, which supply its relative defect in proteid But, at its best, rice cannot be compared with wheat, easily the first of all cereals.

Apart from a proper supply of milk, a proper supply of wheat flour is an essential for the healthy life of any modern nation. We have seen the evidence that this food occupies a special place, in virtue of its richness in the most valuable ingredients of a diet, both those known and those unknown, and in virtue of its remarkable cheapness in proportion to its nutritive power; and we may add that it is also to be valued for the absence of any ingredients which are poisonous or dangerous, nor is it liable to contamination or infection.

And our scheme of national education should comprise courses in domestic science with its study of food-values. Girls should be taught cooking and baking; and these subjects should be associated with the study of domestic economy in relation to food-values. The cause of health would be greatly served by just such a simple reform in education as would teach the women, and especially the mothers, of the nation to spend their money more on wheat and its products and less upon the inferior cereals, to say nothing of meat, which yield no such nutritive return as wheat for a given expenditure.

Courtesy Canadian Pacific Railway

A LIMITLESS HORIZON OF WHEAT
Train of reapers at work in Alberta, Canada.

A MIGHTY FORCE

How High Explosives Are Changing the Face of the Earth

THE WEAPON OF DEATH A SOURCE OF LIFE

OF all the forces over which mankind has obtained control, there is none so mighty and so useful as fire. Yet fire as we commonly know it is but one of a large number of similar phenomena which occur when oxygen combines with other substances. When a tree decays, the oxygen of the air combines very slowly with the organic matter of the tree — it is an affair of years. When a piece of iron rusts, again the oxygen of the air is combining with the metallic iron, and it takes weeks and months. In a burning grate the union of coal and oxygen is quicker — a matter of minutes. In the case of gunpowder or the high explosives used in modern industry and modern warfare, the speed with which oxygen enters into a chemical reaction is practically instantaneous. For instance, in dynamite, the wave of explosion travels at a pace of more than 5000 yards a second. A foot of dynamite explodes in one-24,000th of a second. A mile of dynamite cartridges blows up from end to end in one-fourth of a second; and a much greater speed of reaction occurs in cotton dipped in nitric acid and mixed with glycerine that has also been nitrated.

Chemists have given the name "oxidation" to the type of changes or chemical reactions which result from the tendency of oxygen to combine with other substances. As the few above examples have shown, oxidation reactions are by far the most important type of chemical changes. What we wish to discuss here, however, are only the more rapid kinds of oxidation which take place in the firing of a gun or in an explosion.

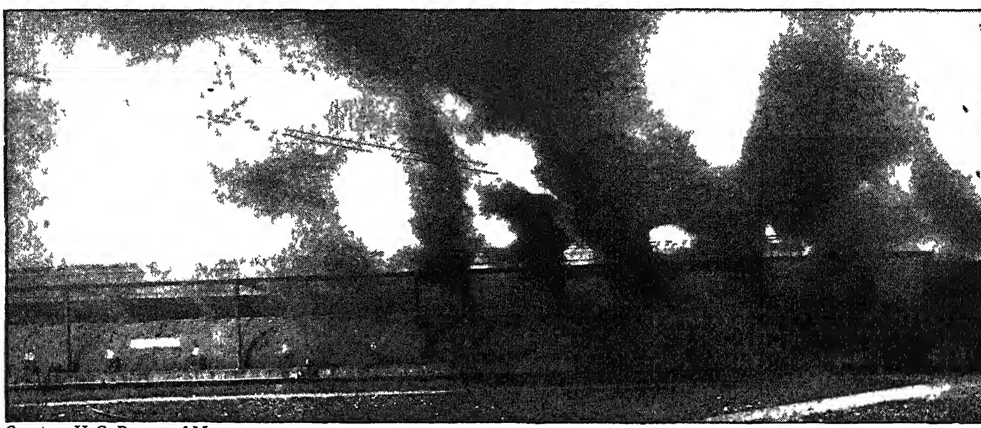
Almost any substance that will burn can be made into an explosive by making it possible for oxygen to combine with it very rapidly. Thus coal in a pile oxidizes very slowly — it would take thousands of years to consume the whole pile if it were kept cool. Once heat it up, which makes the oxygen combine more rapidly, and it will give a bright, warm fire. Blow air, or better yet, pure oxygen into the mass, and it will give a dazzling white heat. Even yet we have no explosion, because it takes too much time for the oxygen to get to the coal. If, however, the coal be powdered extremely fine and mixed with the proper amount of air, it will explode violently when ignited, because each minute particle of coal is now surrounded by oxygen, and can combine with extreme rapidity. Many of the terrible accidents in coal mines are due to this kind of explosion.

Such mixtures of gases and solids would, of course, not be satisfactory for use as military or industrial explosives, since they could not be stored or transported. If, however, we mix finely powdered coal, or better, charcoal, with saltpeter, a solid substance which contains three thousand times as much oxygen (in a given volume) as does air, we have something which could serve as a commercial explosive, since the oxygen and the inflammable material are both in solid form, and yet mixed together very intimately. Each particle of charcoal has its particle of oxygen right at hand in the saltpeter, so that the two can combine with explosive rapidity. These two substances are the basis of ordinary black powder.

Two factors combine to produce the mighty force of an explosion. The first is the fact that the solid explosive, occupying a small volume, is suddenly transformed by oxidation into a huge amount of gas. Thus a cubic foot of nitroglycerine weighing one hundred pounds is changed in a fraction of a second into gases which, when cooled to ordinary temperatures, would occupy more than a thousand cubic feet.

More important even than this, however, is the fact that an explosion sets free a large amount of energy in the form of heat, which heats up and expands the gases to a much greater extent. Probably the gases from the hundred pounds of nitroglycerine, when heated to the temperature which prevails immediately after an explosion, would occupy more than ten thousand cubic feet. At the instant of formation the pressure of the gases is likely 200,000 or 300,000 pounds per square inch — a thousand times as great as the pressure which would burst an ordinary steam boiler. This sudden liberation of a large amount of gas at a high temperature and under an enormous pressure is responsible for all the effects of an explosion. Any container is instantly shattered; a rock or a stump in the path of the expanding gases is swept away like a straw by the wind. The wave of air pressure which spreads in all directions breaks windows and rocks houses even at great distances.

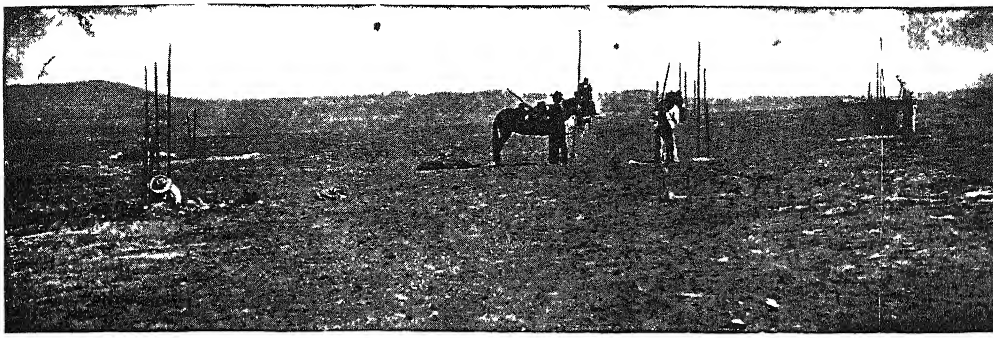
Such is the explanation of the production of one of the truly great forces of modern times. A petroleum lamp burns steadily and slowly by reason of the small supply of air that it obtains. If the air is mixed quickly with the oil, an explosion occurs that can be so regulated as to drive an airplane at the rate of a hundred and seventy-five miles an hour. The automobile is merely a machine for transmitting the regulated power of explosion to wheels. The modern gas engine also derives its power from explosions of gas and air. In all these cases, the oxygen of the atmosphere is intimately combined with oil or gas before the chemical reaction provoked by heat is set up. So, instead of a slow combustion, there takes place a rapid process producing a sudden and violent expansion of gases. The gases strike against the piston of a cylinder and shoot it forward. In this way the motion necessary to drive the wheels of an automobile or the propeller of an airplane is obtained. In other words, a great deal of the machinery in mills and factories and workshops where a gas-plant is used is harnessed to the terrible chemical forces that we hear of in their most sensational forms in connection with war.



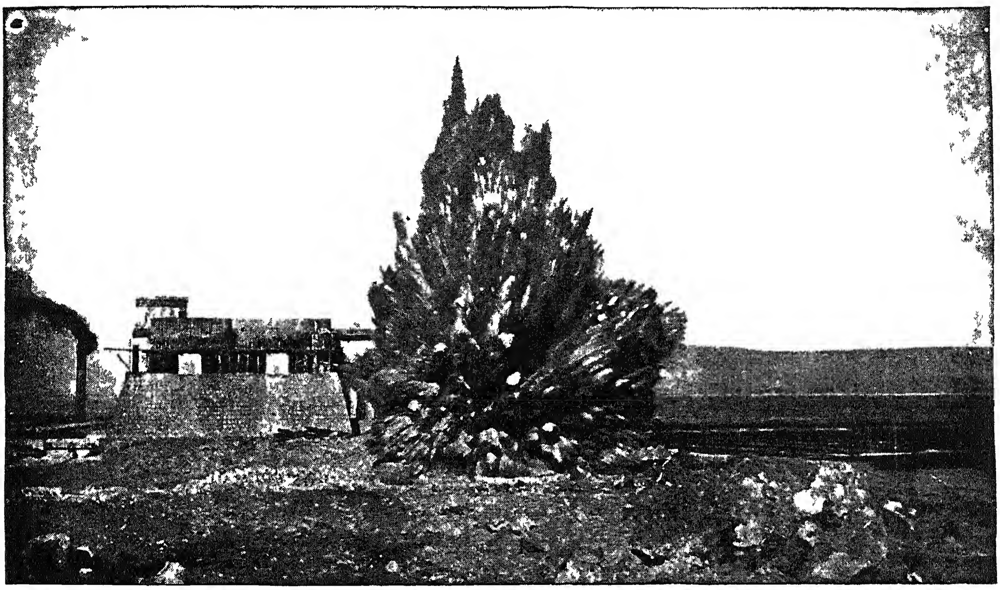
Courtesy U S Bureau of Mines

EXPLOSION OF COAL DUST AND GAS IN THE UNITED STATES TESTING GALLERY AT PITTSBURGH

Though gunpowder was invented by the Arabs in the thirteenth century, and introduced into Christendom by Roger Bacon about 1270, fifty-eight years before Berthold Schwartz, of Freiberg, described it, the industrial use of explosive power



BORING TEST-HOLES IN THE NITRATE FIELDS OF CHILE

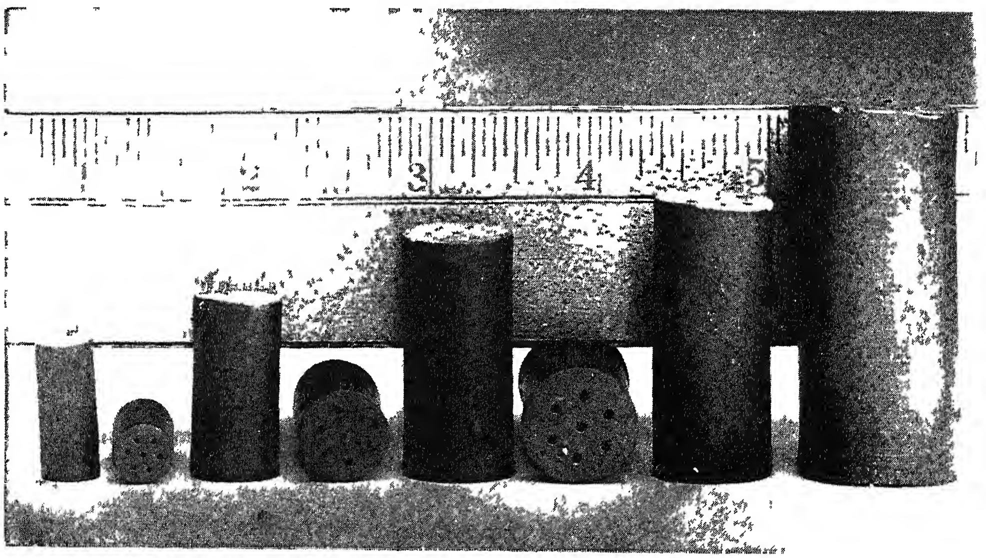


BREAKING UP THE SOIL BY BLASTING A CHARGE PLACED IN A TEST-HOLE

CRUDE NITRATE, OR "CHILE SALTPETER", BROUGHT TO THE SURFACE BY THE EXPLOSION

was neglected for centuries. The science of road-making and mining was scarcely more advanced in the age of Shakespeare than it had been in that of Virgil. Gunpowder seems first to have been employed in mining in 1613, when Martin Weigel, a mine manager at Freiberg, began the excavation of ore by drilling and blasting.

Until the 60's of the last century, gunpowder was the greatest force that man could safely use. In the arts of peace and war alike, a mixture of charcoal and saltpeter, to which was added a certain amount of sulphur, produced the expansive gases with which man killed and dug and tunneled. The United States army standard black powder, which was used almost exclusively until the Spanish-American war, consisted of 75 per cent saltpeter, 15 per cent charcoal and 10 per cent sulphur. As a matter of fact, however, a series of more powerful explosives had been discovered by modern chemists. In 1832, Braconnot transformed starch into a source of terrific power by treating it with nitric acid; six years afterwards, Pelouse and Dumas changed cotton and paper into guncotton and gunpaper by nitrating these substances. In 1846, an Italian, Ascanio Sobrero, treated glycerine with nitric acid, and produced nitroglycerine, which won a tragic notoriety under the name of "blasting oil", for it was a very delicate chemical compound and exploded with the least shock. Being liquid, it ran into the fissures of rock when poured into a borehole; and it required to be carefully confined when exploded by means of a simple fuse. Accidents occurred so frequently that its use was prohibited in several countries and when a ship carrying some of it to Chile was blown up, the event caused such a sensation that it seemed as though the use of nitroglycerine would be forbidden throughout every civilized country in the world.

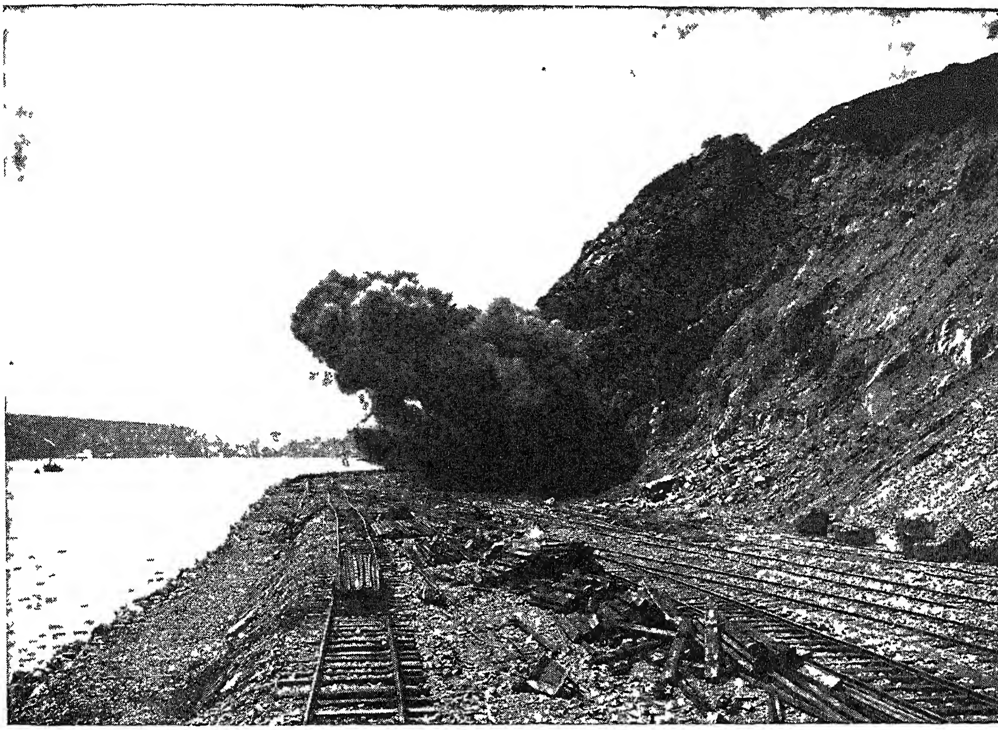


GRAINS OF SMOKELESS CANNON POWDER

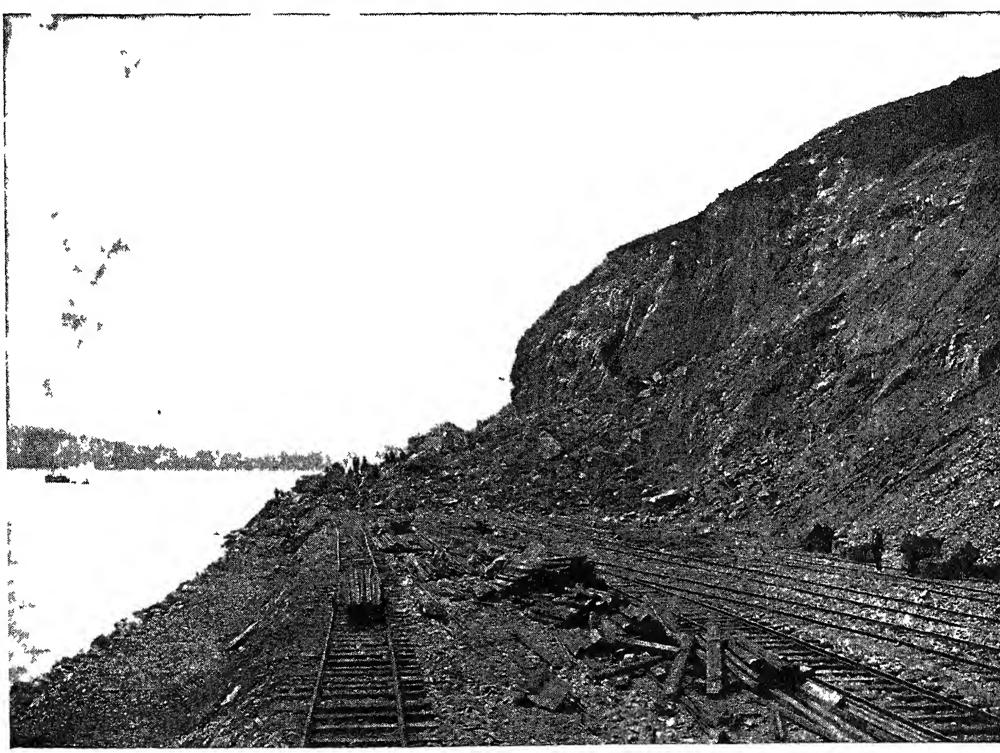
The grains of powder used by the United States government for guns of large caliber are in the form of cylinders with seven perforations running lengthwise through them. When ignited, the perforated grains, being very hard and dense, burn in parallel layers, the exterior with a decreasing, the holes with an increasing surface.

But a Swedish chemist, Alfred Nobel, solved in 1866 the problem of the high explosive. He mixed nitroglycerine oil with a certain kind of porous earth, and produced a stuff somewhat like sawdust, which he called dynamite. Twice as powerful as gunpowder, and much more reliable, dynamite entirely revolutionized the science of blasting. It made possible the execution of the gigantic engineering works of our period, and it brought about that prodigious development of the mining industries of the world which has gone on since 1870.

A POWER THAT REMOVES MOUNTAINS

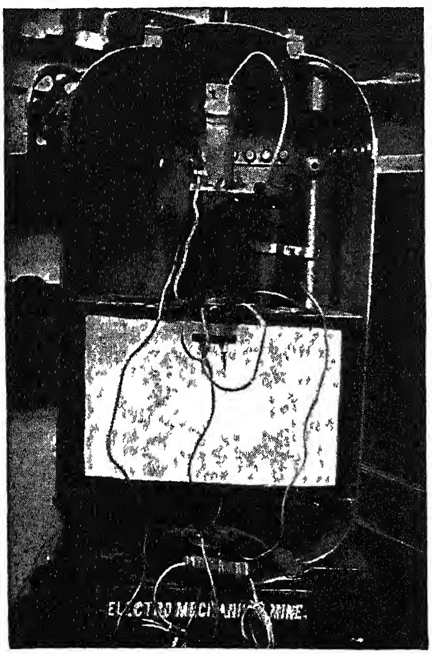


BLASTING AWAY A HUGE MASS OF CLIFF IN RAILROAD CONSTRUCTION



THE DEBRIS RESULTING FROM THE EXPLOSION SHOWN IN THE PICTURE ABOVE

In fact, the invention of dynamite marked an epoch in the history of civilization. It enabled man to change, in a single generation, the face of the earth. By means of it he flung a network of railroads over the continents; he removed mountains from his path; he mined for miles into the fiery heart of his planet; he joined oceans together by blasting away the rock and earth that sundered them; he blew up boulders and stumps of trees that cluttered up many fields and thus he made new lands available for cultivation.



INTERIOR OF A SUBMARINE MINE
The white space is occupied by the explosive, which consists of seventy-five pounds of guncotton

In the ordinary way, dynamite may be kicked about and set alight, and even fired from a gun without exploding. So, too, a considerable quantity of guncotton may be set on fire, and it will then burn quietly. A torpedo filled with wet compressed guncotton will not go off, though a shell from a big gun penetrates the torpedo and bursts in the mass of guncotton. Even nitroglycerine will burn like oil in small quantities, and a stick of nitrogelatine may be lighted without danger.

Many persons, unfamiliar with modern explosives, imagine that shells and submarine mines and blasting compounds are dangerous in themselves, and that to handle any of them would be playing with death. But really the only ticklish part of the affair is the fulminating body, made by dissolving mercury in nitric acid, and adding alcohol to the solution. This is the "setting off", and when it is attached to a high explosive death is very close at hand.

The real trouble with dynamite, from a modern point of view, is that it is not sufficiently explosive. It is safe, because a fourth part of it consists merely of absorbent earthy material which plays no part whatever in the generation of the gases. Formed of the remains of diatoms — a microscopic sea-plant with a hard shell — this material is inactive, and it takes away greatly from the power of dynamite Knowing this, Nobel sought for some years for an active base for his nitroglycerine compound. He wanted a substance which would dissolve in nitroglycerine and form a certain kind of chemical paste.

One morning he was still experimenting in search of the new material when he cut his finger. He sent a man out for some collodion to form an artificial skin to protect the wound. Having used a few drops as a liquid plaster on his cut finger, he was going to throw the rest away, when he thought of trying a mixture of collodion and nitroglycerine. Collodion is made by dissolving guncotton in ether, and the solution so formed is used as a liquid plaster and a varnish and for photographic purposes. When combined with camphor, the dissolved guncotton becomes celluloid. Only moderately strong nitric acid is employed in making this commercial kind of guncotton; it is often highly inflammable, but the camphor makes it inexplosive, and it can be worked with hammers and heavy rollers without any risk. By omitting the camphor, Nobel obtained a mixture of guncotton and nitroglycerine which was remarkably safe, and yet remarkably powerful.

Only the accident of cutting his finger could have led the inventor to experiment with guncotton, for this explosive was the deadliest and most useless of blasting compounds. Guncotton contains too

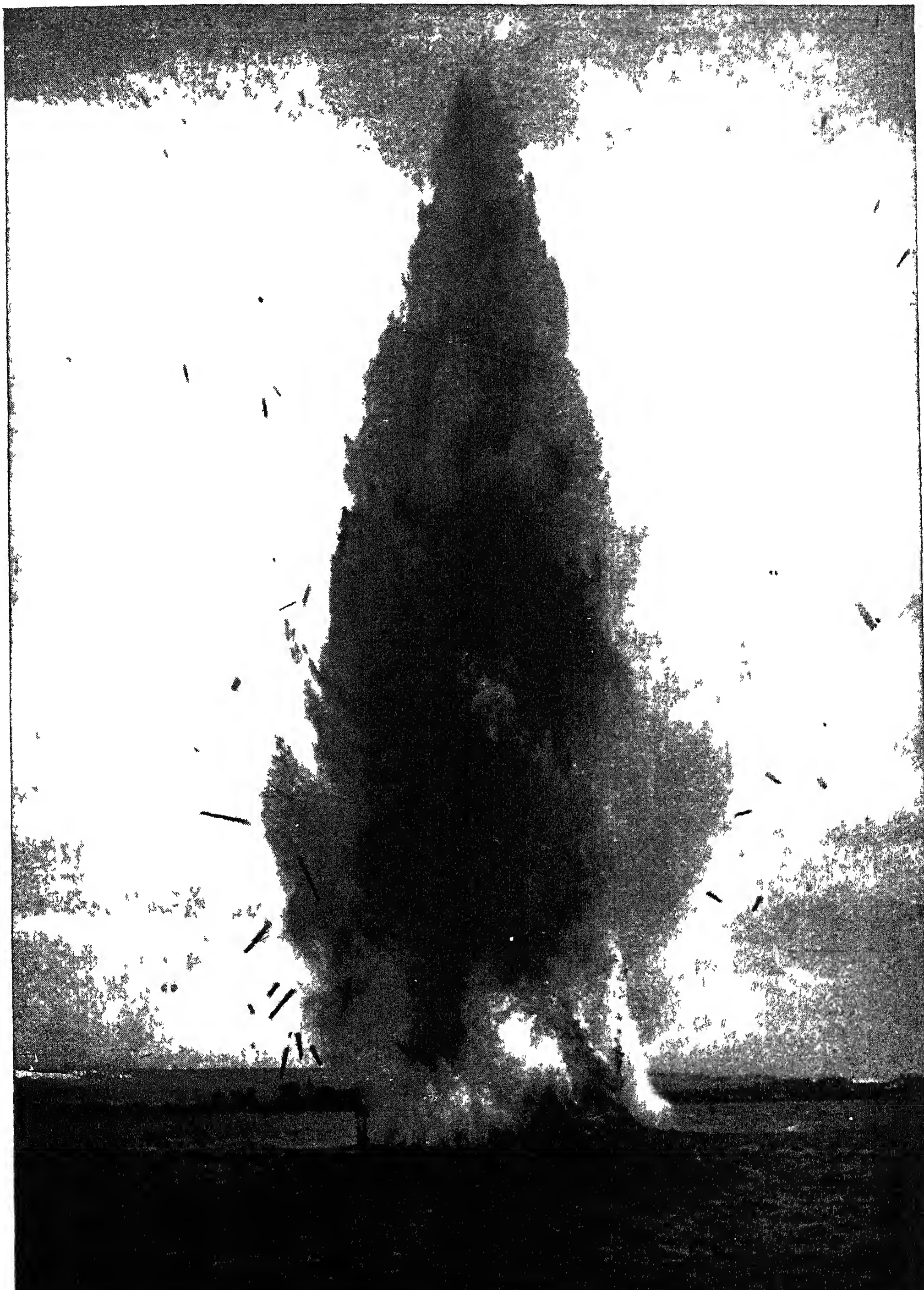


Photo West & Son, from Philip's "Romance of Modern Chemistry

WHAT MODERN HIGH EXPLOSIVES CAN DO

A wooden boom has been blown up and completely disintegrated by a torpedo. Note the immense body of water raised by the force of the explosion.

little oxygen for combustion. The consequence is that when it explodes it gives off poisonous fumes. Thus it was impossible to use it for industrial purposes. Nitroglycerine, on the other hand, contains an excess of oxygen. So when Nobel combined the two explosives in certain proportions, the element that was wanting in one was supplied by the excess contained in the other.

The new explosive was half as strong again as dynamite, and it has been used in large quantities in piercing mountains like the Alps, where the rock is so hard that no satisfactory work can be done without it. Blasting gelatine is one of the most violent forces at the disposal of the human race. In its pure form it can be applied only to the hardest rock. Nobel, however, soon found a way of modifying its terrific action by adding saltpeter and woodmeal to the mixture of nitroglycerine and guncotton. At the present time the use of dynamite has been entirely superseded in some countries by gelatine explosives.

THE PROJECTILE AND CORDITE CHARGE OF A 6-INCH GUN

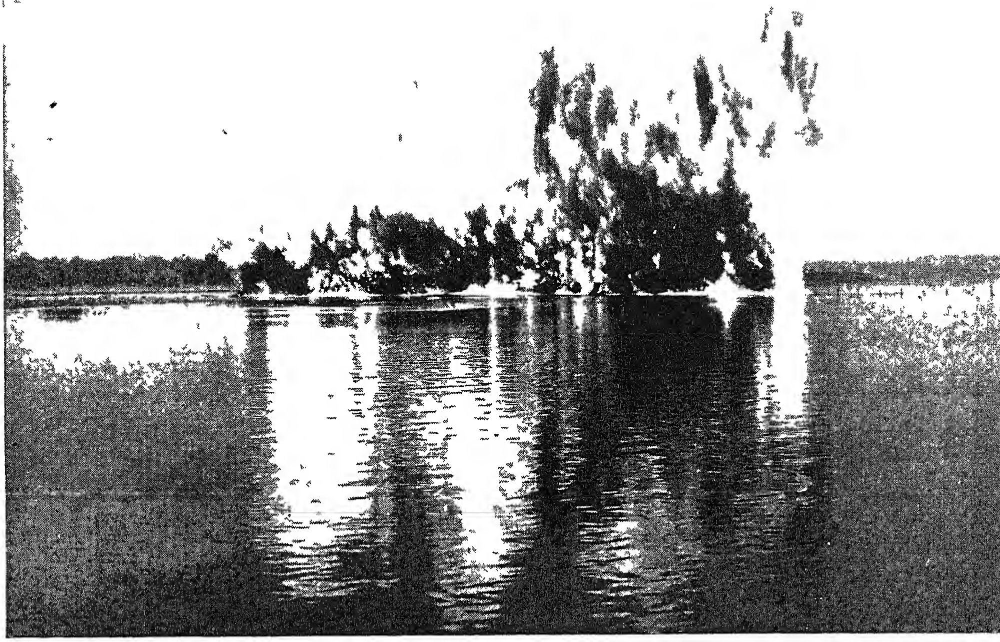
The application of the new high explosives to purposes of modern warfare

It took many years to learn how to apply the new high explosives to the purposes of warfare, and before gunpowder was displaced by the stronger nitric acid preparations in artillery. Even when blasting gelatine was reduced in power by means of moderated substances, it could not be made to fire a gun. So abruptly rapid was the creation of gases that they burst the cannon, instead of driving the shell from the muzzle.

In fact, two different types of explosives are needed for military purposes, known as "propellants" and "high explosives". The propellants are used in rifles and big guns to give a long, steady push to the bullet or projectile, and hence they must not explode too rapidly. The high explosives are placed inside the shells so as to burst them into fragments just over the heads of the enemy. They must therefore explode very suddenly to give a shattering blow, even more violent than that needed in blasting.

The most important component in almost all of the propellent explosives used in modern warfare is guncotton, or nitrocellulose. This is made by treating cotton, or sometimes other substances, such as wool, jute, straw, starch, sugar, etc., with nitric acid, in a manner which will be described later. In its ordinary state guncotton is too unstable and too rapid an explosive for use in guns. Inventors in various countries have therefore modified it in a number of ways. The first form successfully used in a rifled firearm was one invented by a Frenchman, Paul Vieille, and in 1884 adopted by the French government under the name of *Poudre B*, the initial being that of General Boulanger, then Minister of War.

Poudre B was made by adding some solvent to the guncotton, which partly dissolved it and made a doughy mass. This was squeezed out through dies of various shapes, forming ribbons or sticks which were cut into short lengths. When the solvent was evaporated off it left hard, dark brown pieces which burned slowly enough to make a satisfactory propellant.



BLASTING A DITCH WITH DYNAMITE FOR A PIPE LINE ACROSS THE SUSQUEHANNA RIVER

Photos courtesy du Pont Co

CLEARING A FIELD OF ROCKS BY MEANS OF DYNAMITE CHARGES

Warships destroyed by the new smokeless powder

This mixture has since been modified in a number of ways, especially by adding substances to make it more stable, and trying out different solvents. If acetone is used, the pieces are rather brittle, and a mixture of ether and alcohol is therefore more frequently employed.

This *Poudre B* earned a most unpleasant notoriety by the large number of accidents that it caused, especially the total destruction of two of France's best battleships, the *Jéna* in 1907 and the *Liberté* in 1911, catastrophes the more striking in that they occurred in Toulon harbor, in sight and hearing of the whole city. Indeed, before the *Jéna* disaster there had been twenty-four cases of spontaneous ignitions of *Poudre B.* The knowledge of these accidents prevented many of the other countries from adopting this form of smokeless powder

When it was found that the guncotton was liable to decompose with such disastrous results, chemists in France, Russia and the United States set to work to find the cause of this decomposition and the means of preventing it. Their combined efforts resulted in many improvements in the methods of cleaning the cotton, nitrating it, and carefully washing all the acids out of the guncotton. They also found that it was desirable to treat with fresh solvent any powder which was over three or four years old. With these precautions it is believed that the nitrocellulose smokeless powders are as safe as any which could be used

Differences in the behavior of explosives have led to the practice of dividing them into two groups high explosives and low explosives. Gunpowder and explosives of the nitrate class, which includes smokeless powder, are low explosives. Their action is comparatively slow and they are used to lift or push a load without cracking it, or in propelling projectiles. Nitroglycerin and explosives of the class of nitric esters or nitrosubstitution bodies are high explosives. These have a crushing and shattering effect.

Relative advantages of cordite and other explosives

The British government has, however, never been convinced that straight guncotton explosives are as safe or desirable as the cordite which they have developed from another discovery of Alfred Nobel. He found that in spite of the fact that nitroglycerine is far too shattering an explosive to be used in guns, a mixture of about 50 per cent of nitroglycerine with gelatinized guncotton made a very satisfactory explosive. Abel and Dewar of the British government worked out the following process for making it: The guncotton and nitroglycerine are mixed by hand, dissolved in acetone to form a paste, kneaded for several hours by machinery, with the addition of vaseline, and then the paste is forced through a spaghetti machine to form long strips or cylinders. For this reason it was called "cordite". For many years it consisted of 58 parts nitroglycerine, 37 parts guncotton and 5 parts vaseline. In the Boer War, however, it was found that the wear on the guns was so very excessive that the composition was changed to 30 parts of nitroglycerine and 65 of guncotton. Even in this form the life of their big guns is only about half as long as ours, which use straight guncotton, but the British believe that this is compensated by the greater cheapness, dependability and safety of the cordite powder.

Both these types of powders are known as "smokeless powders" because they leave no solid residue, but are completely changed into gases. These new propellent explosives have revolutionized the conditions of warfare on sea and on land. When fired, they produce no smoke to cloud the scene of battle, and they drive bullets and shells to a distance undreamed of by riflemen and gunners of the old school. Naval guns are now in use which can throw at every broadside five and a half tons of steel to a distance of twenty-one miles — often striking forts and ships which are so far away as to be invisible to the men on the battleship itself. The fire is of course directed by men in airships.

Hercules Powder Co

Tamping explosives in a hole that has just been drilled The explosives will be set off by a detonator

Even more terrible than these propellants are the high explosives which are used to burst the shells. The substances used for this purpose must have two rather contradictory properties — first, they must not explode from even such a violent shock as the explosion of the charge of propellant which sends the loaded shell on its long and rapid journey; and second, when the time fuse burns to the end, they must explode instantly and with such violence as to shatter the shell to bits over the heads of the enemy. There are naturally not many substances which fulfil both of these two requirements.

A common coal-tar dye used as a high explosive

Picric acid is the one high explosive most used until recent years. The French melenite, the Japanese shimose and the British lyddite are all composed chiefly of picric acid. It is a coal-tar preparation, frequently used for dyeing, since it gives a bright yellow color on cloth. It was for many years used as a dye before its explosive properties were known except by a few scientists. A terrible explosion in a Manchester dye house first called popular attention to its dangerous properties. Picric acid can be melted to a clear, yellowish liquid which looks much like honey, and can be poured directly into the shell, where it solidifies. The fulminating body at the end of the fuse is almost the only thing which will set it off.

Recently there has been developed a new and better explosive known as tri-nitro-toluene. This is also a coal-tar product of very similar composition to picric acid. Although the tri-nitro-toluene, known the world over as T N T, is a more violent explosive than even picric acid, it is nevertheless the safest to handle of any of the common explosives. Yet when a giant shell loaded with T N T reaches the proper place in its flight, and explodes, there is a literally deafening report, and when the cloud clears away the very face of the earth is seen to be changed. A huge crater is dug in the earth, trees are uprooted and the hardest rocks are ground to powder.

How explosives are made and some of the safeguards used to protect the makers

Since the majority of explosives used for military and industrial purposes consist of nitroglycerine, guncotton, or mixtures of the two with other substances, it will be of particular interest to describe their method of manufacture somewhat in detail.

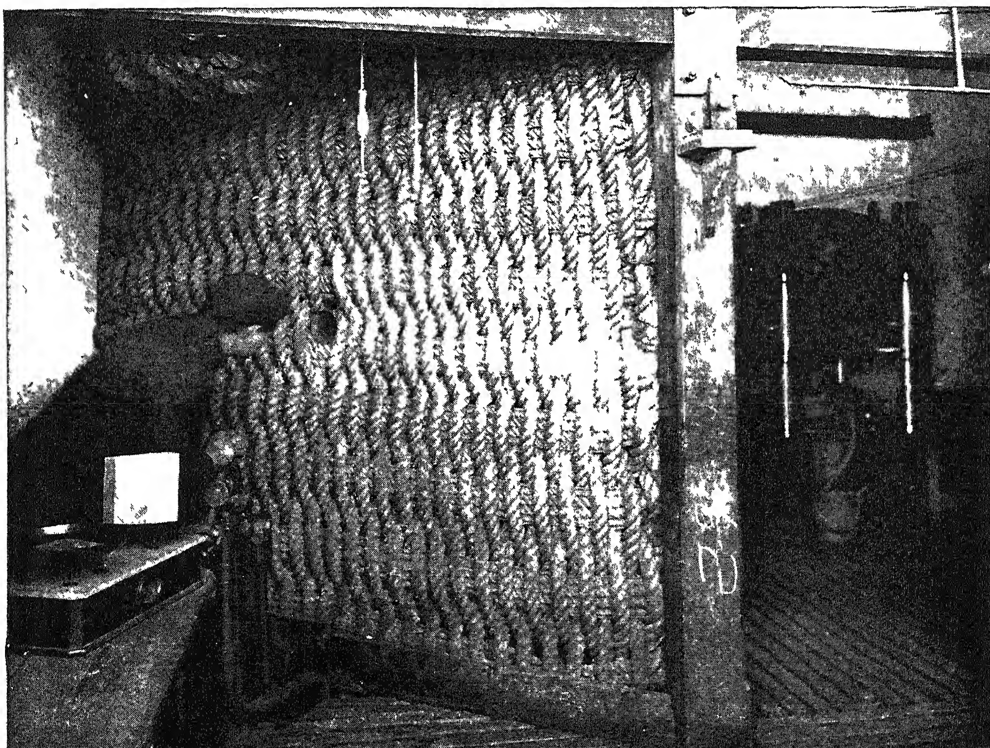
In the United States guncotton is made from the short cotton fibers picked off seed of the cotton as it comes from the gin. In England they use chiefly the clippings and waste from cotton mills The stuff is first picked over and cleaned from oil and grease and dirt, and then carded and cut into short lengths. After this, it is well washed and dried in steam-jacketed cylinders, about five feet long and one and a half feet wide. The dipping is done in cast-iron tanks, holding about twelve gallons of strong nitric and sulphuric acids. The sulphuric acid does not add in any way to the explosive power of the guncotton. It is used merely as an absorbent, to prevent the water, which is formed during the process, from weakening the nitric acid, and this allows the real explosive elements to expand into gases without any lessening of their strength.

The cotton is thrown in the tank a pound at a time, and moved about by the workmen with an iron rabble. When thoroughly wet, it is lifted on to a grating above the tank, and there it is squeezed until it only contains about nine times its weight of acids. That is to say, a pound of cotton after being dipped should weigh ten pounds.

The steeping process has then to be carried out. The dipped cotton is placed in earthenware pots, which are set in rows in large cooling-pits, a foot deep, through which water is kept running. For forty-eight hours the cotton remains in the pots, and great care has to be taken to keep it quite cool. If all goes well, the chemical reaction is completed at the end of two days, and the cotton is entirely transformed into a new chemical compound, which is called "nitrocellulose"

Guncotton is one of the least dangerous of the nitro compounds to manufacture. It is often drained in a whirling machine that makes from a thousand to fifteen hundred revolutions a minute; and it is pressed by hydraulic power into blocks weighing a quarter of a ton, for use in torpedoes and submarine mines. A good many people now comb their hair with guncotton and handle it at all their meals. For, as we have already explained, two parts of liquid guncotton and one part of camphor form the celluloid out of which combs and knife-handles and innumerable other articles of daily use are manufactured. Yet when guncotton was first made in bulk, some dreadful explosions occurred in the factories, for a little pressure was sufficient to detonate the compounds.

The manufacture of nitroglycerine, however, is still a somewhat perilous operation. It is performed in a set of danger buildings placed in a danger area. The buildings are at different levels, down which the liquid explosive flows through lead-lined wooden pipes, from one house to another. No iron or steel or brick or stone is used in the construction of the danger buildings. They are made of wood, which offers much less resistance than hard material. Usually, when an explosion occurs, the sides of the house are blown out, and the roof goes up in the air and tumbles back on the blown out walls. Had the explosion occurred in a strong brick or stone building, large fragments of the material would have been shot at the surrounding edifices. The best plan, it has been found, is to sink all the danger buildings in pits and surround them with ramparts of turfed earth, standing higher than the roof of the house of peril. In this way the effects of the disaster are confined to the spot at which it occurs.



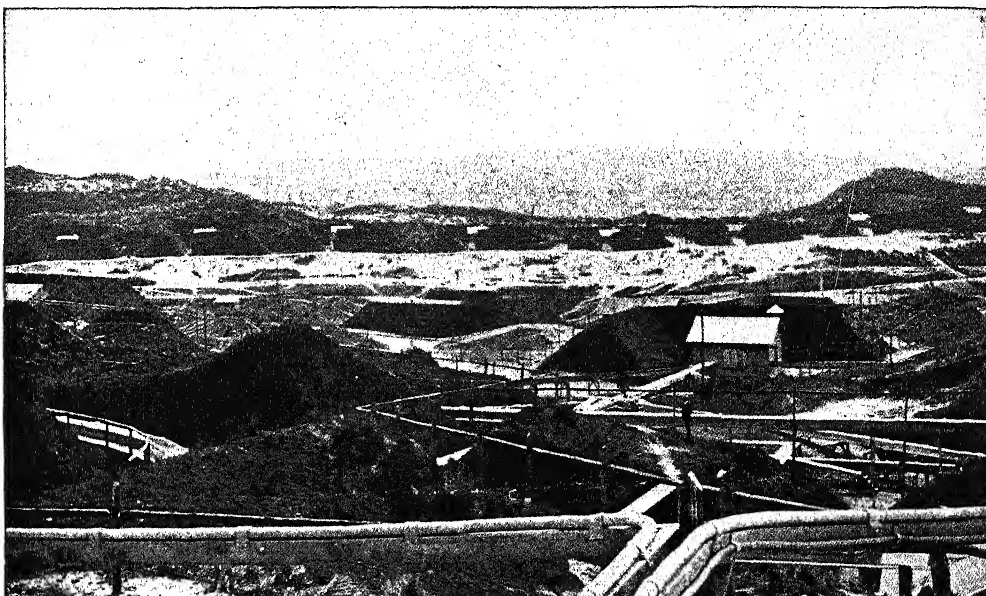
WORKING UNDER COVER

In the background is a guncotton press, and the workman in the foreground who operates the machine is protected in case of accident by the rope screen through which he is peering

In nitroglycerine works every effort is made to prevent any possibility of a slight shock, a scratch of metal against stone, or any such trivial disturbance which might set off the whole factory. The workmen must wear shoes of sewn leather, for nails are much more dangerous than lighted matches. All the tools are made of bronze or brass, and the buildings are kept together by wooden pegs or brass nails. Explosions have resulted from such slight causes as the action of sunlight on a bucket containing water which had been used in washing nitroglycerine. So, altogether, a worker in a nitroglycerine factory does not have a dull life. His conditions of work are being steadily improved, however, and the process is not nearly as dangerous as formerly. The workmen on entering must change all their clothes, and are not allowed to bring in any pieces of metal, matches, cigars or cigarettes. The nitroglycerine gets into the workmen's clothes and if he wore them home, he would be a sort of walking torpedo, liable to go off on the slightest provocation.

The first stage in the making of the explosive takes place in the nitrating-house, which is kept scrupulously clean of grit and sand and dirt. Through a window in a large tank of lead, the operator watches a stream of glycerine flowing into a mixture of sulphuric and nitric acids. Under his control is a current of compressed air, that keeps the liquids well agitated during the process of nitration. A thermometer indicates the temperature of the mixture, and the greatest care must be taken to prevent the heat produced by the chemical reaction from raising the temperature beyond the danger point. A constant stream of water circulates round the tank and cools the mixture, and the current of compressed air also serves to lower the temperature. It takes about thirty minutes to complete the nitration; and when this is done the raw nitroglycerine is ready to run to the separating-house.

It is a heavy, oily liquid, of a pale straw color, with a sweet taste and rather poisonous qualities. Some persons cannot let it touch their skin without getting a headache, and unless it is kept cool it is liable to explode.

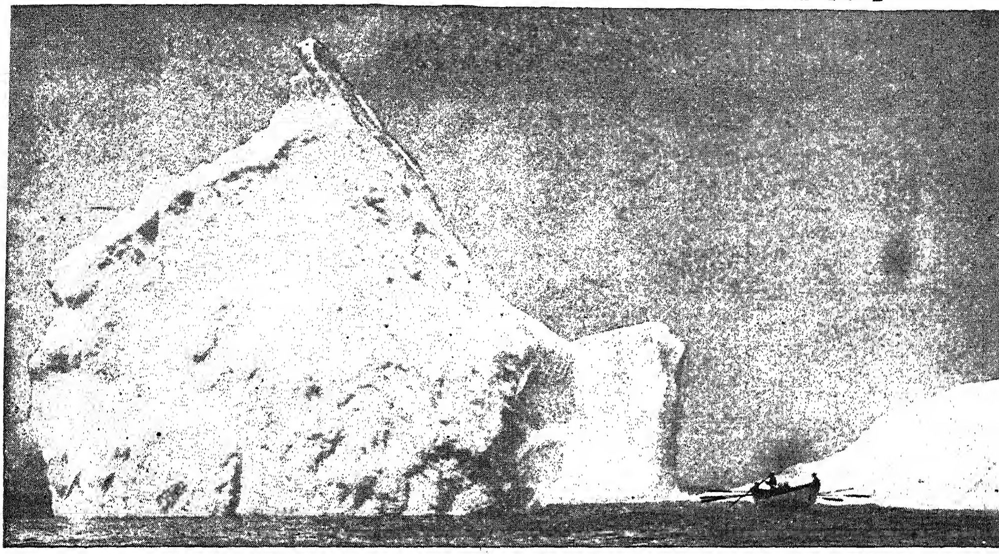


From Philip's "Romance of Modern Chemistry", and by permission of Oscar Guttmann & Sons

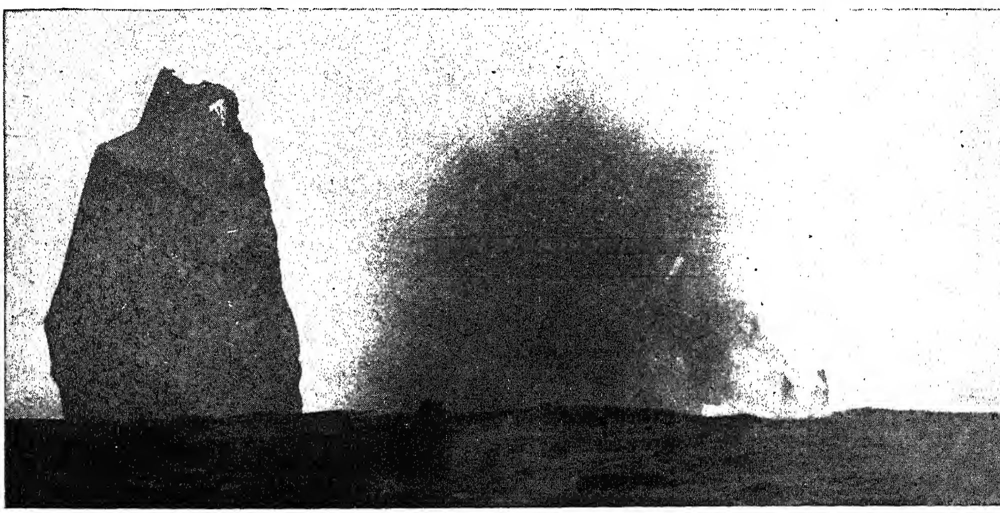
A DANGER AREA

A dynamite factory in England. The scattered sheds for the various stages of the manufacturing process are separated from each other by earthworks, so that in the event of any explosion the damage is localized. The pipes convey water and acids to the separate sheds.

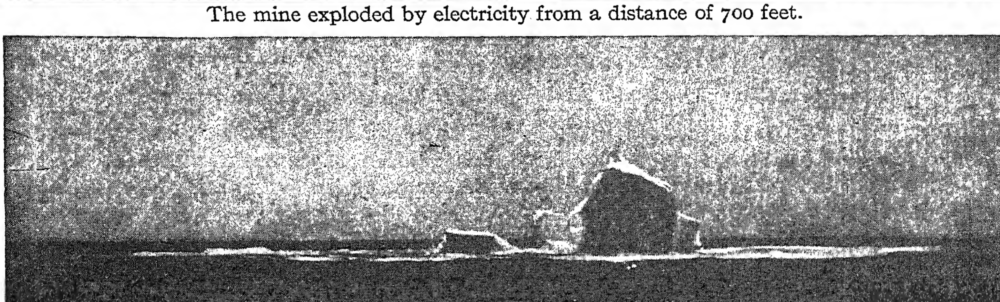
EXPLODING AN ICEBERG WITH TNT



Pulling away after attaching the mine to the 1400-foot berg.



The mine exploded by electricity from a distance of 700 feet.



"When the smoke cleared away only three small cakes were in sight."

U. S. COAST GUARD CUTTER *TAMPA* DISPOSES OF A DANGER TO NAVIGATION

Photos Lieutenant R. T. McElligott.

The liquid, then, flows from the nitrating-house to the separating-house. Here it becomes very dangerous. The separating-tank is also fitted with a window; and as the waste acids run away from the nitroglycerine, a workman watches for the appearance of the vivid red fumes which are the danger signal. Whenever the smoke grows red, the pressure of compressed air must be increased to mix up the charge that is getting too hot through chemical decomposition. This decomposition is provoked by the water, with which the nitroglycerine is washed two or three times. If the fumes cannot be kept down, and an explosion is likely to occur, the tap between the separating-tank and the drowning-tank is swiftly opened. The nitroglycerine then runs away into the drowning-tank, which is a large cooling-cistern placed outside the house.

But if all goes well, the charge, after being separated from the waste acids and well washed in water, flows down the lead pipes into the large filter-house. Here it is drained through two flannels, and then drawn off in rubber buckets and tested by the chemist. Very often it does not pass the test, and has to be rewashed. When the chemist is satisfied with its qualities, it is poured down the pipe running to the settling-house. It stands in conical tanks three or four feet high, and remains in them for a day or more, to allow the water it contains to rise to the surface. Sometimes it is filtered through common salt, which keeps back the water, and thus shortens the time needed for the settling. In powder factories there are many other ingenious devices to diminish the risk of manufacture and obtain a highly purified chemical compound.

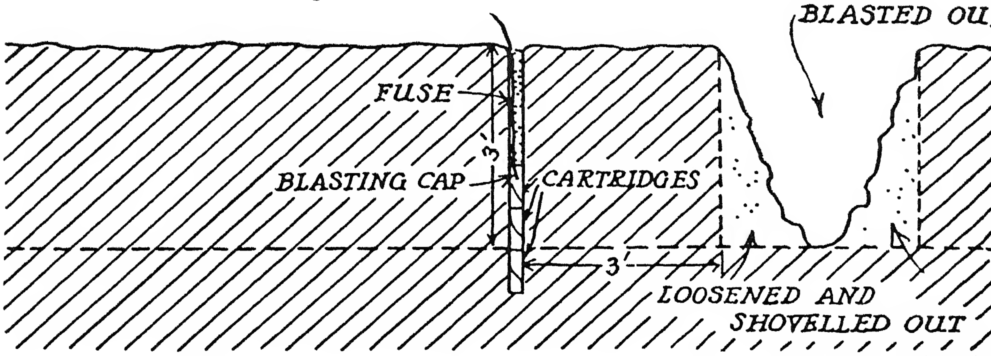
After the nitroglycerine has settled, it is ready to be made into dynamite, or compounded into cordite, blasting gelatine or various other explosives. Dynamite is made by mixing the nitroglycerine with infusorial earth, or kieselguhr, which will soak up three times its weight of nitroglycerine; but for blasting purposes a weaker mixture is used. It is taken to the cartridge huts, in each of which there are three girls. One works the press, which is a cylinder with an ivory piston which pushes the charge into the cartridge. The other two girls wrap up the cartridges, and about every ten minutes a boy comes to the hut and collects the dangerous product.

For mining operations dynamite has largely been supplanted by blasting gelatine and various special powders, usually containing some nitroglycerine, which are more powerful, cheaper, less affected by water, or safer to use in a mine than dynamite. Many of the so-called "safety powders" are very much like dynamite, but have some added substance which reduces the temperature and the length of the flame of a dynamite explosion. Although this cuts down the force of the explosion, it is a desirable change since the flame from a small charge of dynamite has a number of times been known to ignite some fire-damp, or coal-dust, and cause disastrous mine explosions. For some other kinds of blasting work dynamite is also being supplanted by various types of explosives especially designed or adapted for a particular set of conditions. The function of each substance entering into explosives is now so well known by the experts that they can make some explosive mixture which will have almost any desired set of properties.

In modern blasting there is little danger when the men are careful, for all explosives used for industrial purposes are tested in many ways before being put on the market. Usually, industrial explosions in mining and engineering are performed by a shot-firer, working an electric current from a safe shelter. Little is left to chance, for men have learned by experience to control the tremendous force of the gases. This they do by boring shot-holes in the rock or coal they wish to dislodge, the depth and direction of the holes and the amount and the quality of the explosive determining almost exactly the nature and extent of the work performed by the fired charge. Some explosives drive a wedge through a hard material when they go off; others act like a tremendous steam-hammer, and deliver a smashing, crushing blow.

New uses for dynamite; the sword of war beaten into the plowshare of peace

Although dynamite is thus being supplanted, it has found a new field of industry in which it is said to have produced some remarkable results. Dynamite has for a long time been used in agricultural work in preparing new lands for tillage — blowing out stumps and rocks, draining marshes, etc. More recently it has been used extensively in digging the holes for setting out fruit trees and vines. With the present high prices of labor it is found to be actually cheaper to dig holes this way than by hand. But, strange to say, trees planted in dynamited holes are found to thrive much better than those planted in the older way. This may be due in part to a slight fertilizing action of the dynamite, but the more probable causes are the loosening up of the earth for yards around, and the killing off of minute animals and organisms which would otherwise prey upon the young trees and prevent their growth.



Institute of Makers of Explosives

METHOD OF LOADING DYNAMITE FOR BLASTING CELLARS AND VARIOUS OTHER EXCAVATIONS

The most recent development in agricultural uses for dynamite is for the so-called "deep plowing". As is well known, a considerable part of our rich virgin soil has been exhausted by the farmers taking crop after crop off it without putting any manure back into the impoverished earth. They found it more profitable to move to newly opened tracts when they exhausted the soil in one locality. This selfish policy resulted in the decline of many once prosperous farming communities. for no one cared to run a farm with an unfertile top soil, and the amount of fertilizer necessary to bring it back into good condition would cost an excessive amount. It has been found, however, that if, instead of merely plowing over about six inches of soil each year, dynamite be used to break up the ground to a depth of five or six feet, many of these old farms may by this means be reclaimed, and by pursuing a proper fertilizing policy, they may be farmed indefinitely. An expenditure of $10 or $15 per acre for dynamite will often turn a worn-out farm into one almost as good as new. The weapon of death has indeed proved to be a source of life — furnishing food for thousands of families instead of robbing them of their bravest sons.

Indeed, without explosives, and the hundreds of men who daily risk their lives to make them, the two hundred thousand acres of desert land in America that have recently been irrigated by the Roosevelt Dam would still be a wilderness; the Panama Canal would not have been built; the United States would think of turning to Canada for bread for her vast and still growing population; thousands on thousands of miles of roads and railways now existing would still be waiting to be made; and coal and other important minerals would be less abundant and dearer in cost. In short, the entire industrial development of the world would have been seriously impeded, with the result that the population of the highly civilized races would have either been restricted in growth or compelled to adopt a lower standard of life.

THE HIGHEST GEYSER IN THE WORLD

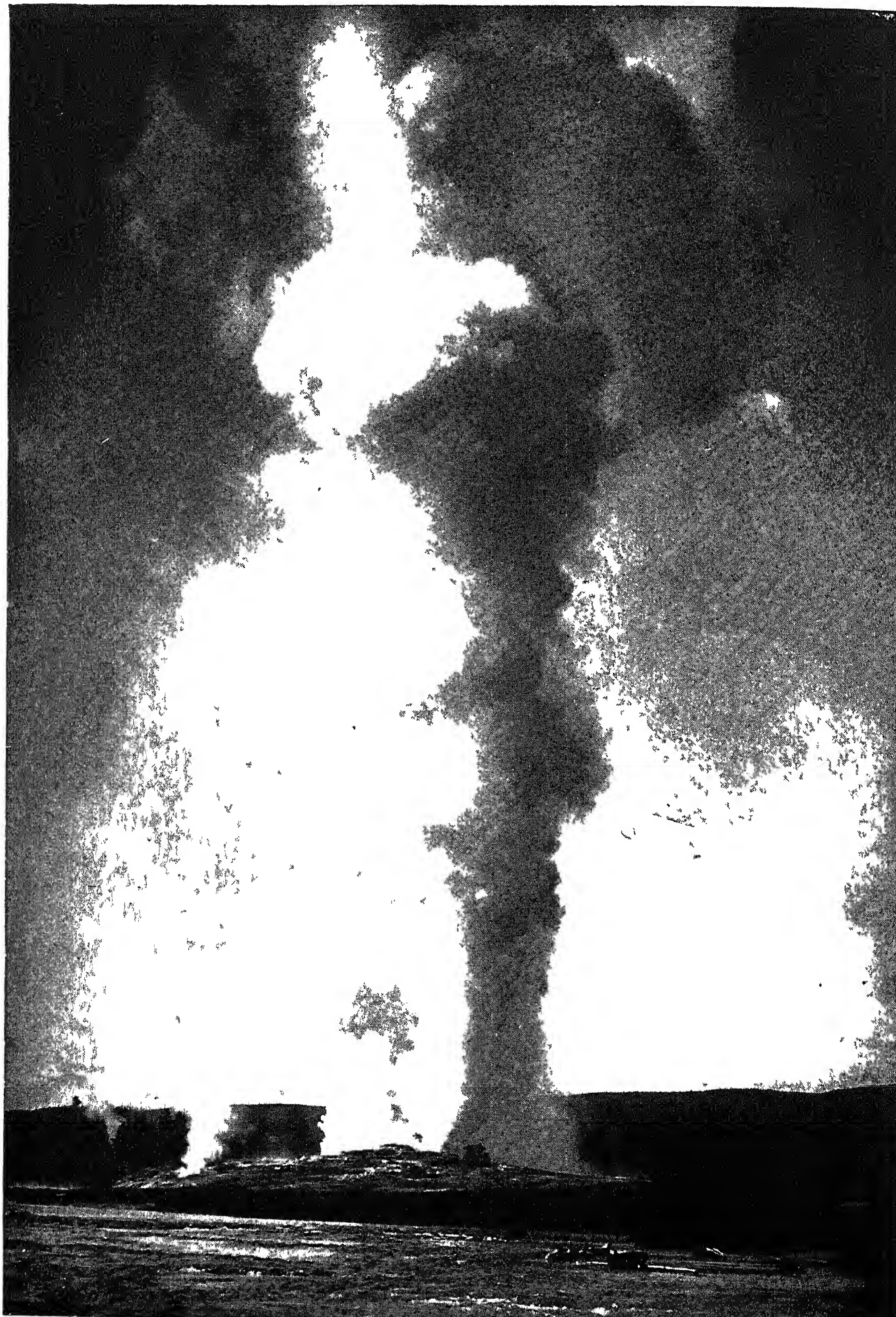


Photo J E Haynes, St Paul

GIANT GEYSER (250 FEET), YELLOWSTONE NATIONAL PARK

GEYSERS AND VOLCANOES

The Various Forms Through Which the Earth's Internal Heat Bursts Forth

WAS OLD OCEAN MADE BY VOLCANO STEAM?

AMONG the minor but still highly picturesque evidences of the igneous agencies in the earth are certain hot or boiling springs called geysers The term "geyser", derived from an Icelandic word meaning to gush or to burst forth with violence, is applied to those actively boiling springs which at intervals throw out columns of hot water and steam. These springs, associated with volcanic activity, appear to be restricted, as far as is known, mainly to three regions, Iceland, New Zealand and our own Yellowstone Park. Geysers were first studied in Iceland and in the North Island of New Zealand, but neither of those countries can claim the great number and varied beauty and activity that characterize the geyser fields of the United States In the heart of the American Rockies, in the northwest corner of Wyoming and extending into Montana and Idaho is the wonderland of natural phenomena known as the Yellowstone National Park. In 1872 Congress set apart 3575 square miles in this region "as a public pleasure ground and game preserve". In 1891 another large tract was added to the park, making its area 5600 square miles, nearly three times as large as the state of Delaware. The Yellowstone Park is remarkable for its grand scenery, many snow-clad peaks, a dozen or more over 10,000 feet high, lying within and near its borders, but its main attraction is the constantly recurring phenomenon of minor volcanic agencies, over one hundred geysers and more than three thousand hot springs.

There are three great geyser basins in the valley of the Firehole River, all about 7000 feet above sea level. The upper is the most active, containing the Giant and Giantess, named from their great crater-size and force of action, the Beehive and Castle, so called on account of the shape of their cones, the Saw Mill and Lion, from the noise they make, and Old Faithful, from its regularly recurring eruption. The Giant spouts every six days, throwing a column of water and steam 10 feet in diameter to a height of 200 feet; this action held once for three hours, but usually lasts only a few minutes.

The most dependable of the well-known geysers is Old Faithful which ejects a spectacular column of steam and water with remarkable regularity. The eruption occurs on the average every 66½ minutes, the maximum interval being 115 minutes, and the minimum 38 minutes, although the usual range is much smaller, hovering between 62 and 68 minutes. The average height of the eruption is 146 feet. It has risen to 184 feet but has never been measured at less than 111 feet.

The Miniature Geyser, the smallest on record, spouts its water only a foot high. In describing the Castle Geyser, Lord Dunraven in "The Great Divide" said:

"Far down in his bowels a fearful commotion was going on ; we could hear a great noise — a rumbling as of thousands of tons of stones rolling round and round, piling up in heaps, and rattling down again, mingled with the lashing of the water against the sides as it surged up the funnel, and fell again in spray. Louder and louder grew

the disturbance, till with a sudden qualm he would heave out a few tons of water, and obtain momentary relief. After a few premonitory heaves had warned us to remove to a little distance, the symptoms became rapidly worse; the row and the racket increased in intensity; the monster's throes became more and more violent; the earth trembled at his rage; and finally, with a mighty spasm, he hurled into the air a great column of water. I should say that this column reached, at its highest point of elevation, an altitude of 250 feet. The and stronger at every pulsation for ten or twelve strokes, until the effort would culminate in three impulses of unusual power. . . . The volume of water ejected must have been prodigious; the spray descended in heavy rain over a large area, and torrents of hot water, six or eight inches deep, poured down the sloping platform."

In the Middle Basin of the Firehole region is "The Devil's Paint Pot", a caldron of boiling, many-hued mud which bubbles and steams with a wonderful play of changing colors.

Photo J E Haynes, St Paul

CASTLE WELL AND CASTLE CONE

spray and steam were driven through it up to a much greater elevation, and then floated upwards as a dense cloud to any distance. The operation was not continuous, but consisted of strong, distinct pulsations, occurring at a maximum rate of seventy per minute, having a general tendency to increase gradually in vigor and rapidity of utterance until the greatest development of strength was attained, and then sinking again by degrees. But the increase and subsidence were not uniform or regular; the jets arose, getting stronger

The hot water ejected by geysers is always beautifully clear, but still it is highly charged with mineral matter, mainly dissolved silica, and round the orifices of the geysers there are incrustations of such matter that often assume beautiful or fantastic forms and colors. Thus, the Castle Geyser has made a beautiful white cone for itself, and the Great Fountain Geyser a broad, circular pedestal about two feet high. The tints assumed by the mineral deposits are produced by algæ, which grow luxuriantly in the hot water.

The amount of water discharged by geysers is very large. The Excelsior Spring, even in its most dormant condition, pours out over 250,000 gallons an hour into the Firehole River; and Old Faithful, 10,000 to 12,000 gallons per eruption.

Though Yellowstone Park boasts of the most numerous and famous geysers, Iceland, the birthplace of geyser study, must not be passed by without notice. This country is itself one of the wonders of the world — weird, grotesque, and sinister — a wonder of desolation. It is a land of fire and ice, of glacier and geyser, of lava and slush, of avalanche and volcano. Here "Nature breeds all monstrous, all prodigious things". It has no green fields, nothing but "raw-white and dull-black hues, like gulls' feathers strewed upon a roof of tarred shingles". An Icelander once described his native land as "nothing but bogs, rocks, precipices; precipices, rocks and bogs; ice, snow, lava; lava, snow and ice; rivers and torrents, torrents and rivers".

From the top of Odahahraun, a lava field extending over 1700 square miles, the surface of the earth resembles a gigantic, stiffened corpse, petrified, black as the night. All together, no less than 5000 square miles of the island are black with lava, and 5550 square miles are white with snow. Rising from this black-and-white desert are great volcanoes, such as Hecla (5110 feet). Most of the volcanoes are quiescent now, but Askja, whose crater is 34 square miles in extent, and 3000 feet deep, was in eruption in 1875, and covered about 2000 square miles with its ashes.

In a young volcanic district such as this it is not strange to find geysers; they are only one of many signs of volcanic activity.

The Great Geyser has built a mound of siliceous material for itself about 40 feet high, and from the saucer-like basin on its top a tube 10 feet in diameter descends about 74 feet. In its prime, it used to eject water to the height of 150 feet, but now the average height of its jet is only 70 or 80 feet. The sound of the geyser in eruption has been compared to the roar of an angry sea intermingled with the regularly recurring sounds of minute-guns.

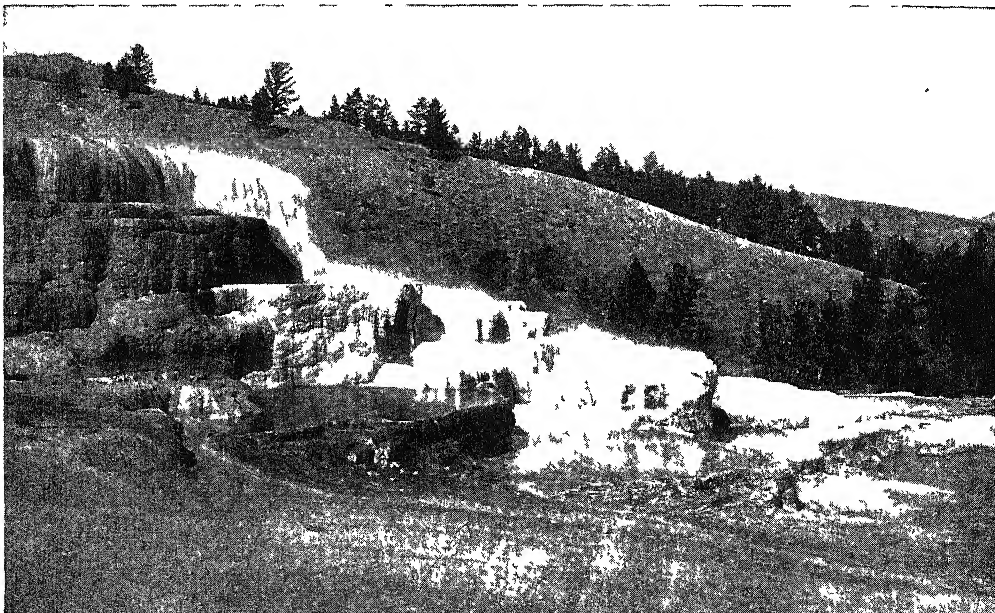
The Strokkr has no regular basin, merely a funnel-shaped tube, narrowing from a diameter of 9 feet at the surface to 10 inches at 27 feet down It can usually be made to erupt by throwing in turf or stones, the amount thrown in regulating the time of eruption. The Strokkr can spout higher than the Great Geyser, but its usual height is only 30 or 40 feet.

A third great geyser wonderland is found in the North Island of New Zealand, in the volcanic country round Lake Taupo and Rotorua. Here we find the greatest geyser in the world Its tube, 80 feet deep, is situated in the middle of a hot lake lying in a crater formed during the great volcanic eruption of 1886. This tremendous geyser has not the beauty of the Yellowstone Park geysers, since the column of water it flings is muddy and inky-black, but it surpasses the Yellowstone Park geysers in violence, since it often throws its water column to a height of 500 feet, and on one occasion three times that height. At times it is dormant for weeks, and at other times it is active for weeks. Near Rotorua there are a number of geysers, but only the smaller ones are now active, and the Wairoa Geyser, which used to spout spontaneously to a height of 200 feet, will now play only when fed with bars of soap.

It has been found that the addition of certain alkaline substances, like soap or lye, makes the water somewhat viscous, causing it to retain the smaller steam bubbles till the accumulated volume of steam breaks out with a sudden lowering of pressure and increased eruptive power. Before the great eruption of 1886 two geyser lakes by their overflow had produced these marvelous siliceous encrustations known as the White and Pink Terraces. At the eruption these were destroyed. The White Terrace had about forty secondary terraces, and rose to a height of 150 feet, and the Pink Terrace was built up in fifty steps, and rose to a still greater height. Many a pen has tried in vain to describe their exquisite beauty. Those who have seen Cleopatra Terrace and Jupiter and Minerva Terraces in our own Yellowstone Park can readily imagine what they must have been like.

Before leaving the subject of geysers, let us look for a moment at the manner of their action Expanding steam is evidently the motive power of the active geyser. The steam is most probably produced by contact of underground waters with heated rock masses, or hardening lava, or by hot gases and vapors emitted by neighboring pockets of molten rock. The explosive and intermittent geyser action is explained best by the theory developed by Bunsen during his study of the Great Geyser in Iceland.

The boiling-point of water is lowered and raised as the pressure at the surface of the water is diminished or increased. Under ordinary atmospheric pressure at sea level, water boils at 212°. At the top of a mountain, where the atmospheric pressure is less, it will boil at a much lower temperature; at the bottom of a deep mine, where the atmospheric pressure is greater, a higher temperature is required. Now, in a deep pipe the water at the bottom is under the pressure of all the water above it, and so it requires a temperature of more than 212° F. to raise it to boiling-point, or, in other words, to convert it into steam, while water in the middle of the tube, being under less pressure, will boil at a rather lower temperature. If the tube be wide and somewhat regular in shape convection currents will carry the highly heated and lighter lower layers to the top, equalizing the temperature, and if the heat is sufficient an ordinary boiling spring will result. If, however, the pipe is irregular, tortuous and constricted at some point, ascension of the heated bottom layers is stopped or partially checked, their temperature rises higher and higher, going above the ordinary boiling-point 212° F. on account of the pressure of the water above. Any decrease of pressure, coming from the overflow of some of the upper-pipe water into the basin, will cause the water at and below the constricted part, already above the ordinary boiling-point, to flash into steam. A column of mixed steam and hot water is shot out; some of the water may return, more flows in from the rock fissures and the phenomenon is repeated with more or less regularity according to the supply of water and heat. A laboratory model built and operated on this theory works perfectly. Of course, lessening of heat and choking of the water conduits will diminish geyser activity.



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CLEOPATRA TERRACE, YELLOWSTONE NATIONAL PARK

Volcanoes and geysers must be considered together, for they are undoubtedly akin. Geysers are just a kind of volcano, and volcanoes are just a kind of geyser, but volcanoes are much more magnificent manifestations of force. They are, indeed, the most impressive of all nature's forces, with the one possible exception of earthquakes. All over the world volcanic craters are glowing and steaming, grumbling and grumbling; and ever and anon, in paroxysms of violence, they devastate the land with clouds of fire and steam, with broadsides of boulders and rocks, with rivers of lava and hot mud. Vesuvius, Etna, Hecla, Stromboli, are familiar names of fiery fountains. To our forefathers they seemed the porches of the infernal regions.

A volcano is a vent or fissure in the earth's crust, from which emerge, more or less violently, solids, liquids and gases, hot and incandescent, which materials sooner or later build up a cone about the vent. The term is now applied to the conical mountain, whether it be active, as Stromboli, or dead, as the Puy-de-Dôme in France. Such hills and mountains may be of all shapes and all sizes, but they are usually conical and often very lofty. Orizaba and Popocatepetl, in Mexico; Cotopaxi and Aconcagua, in the Andes; Mount St. Elias, in Alaska; Kilimanjaro and Kenia, in Africa; Ararat and Damevend, in Asia, are all between 17,000 and 23,000 feet high. Many of their conical peaks are beautiful and picturesque The Peak of Teneriffe (12,192 feet), rising from tne sea; Etna (10,570 feet), girdled by the Sicilian surf; Chimborazo (20,000 feet); and especially, Mayon (8970 feet), Philippine Islands, Mt. Osorno (7500 feet), Chili and Fujiyama (12,390 feet), Japan are all remarkable for beauty and regularity of shape, the last two being snow-capped.

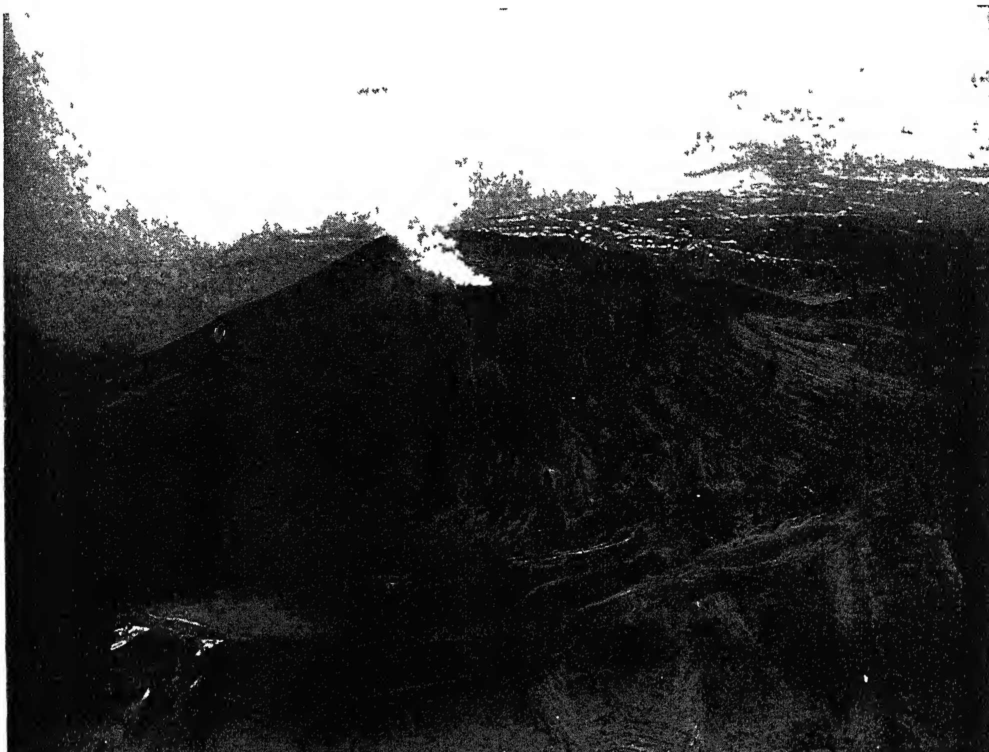


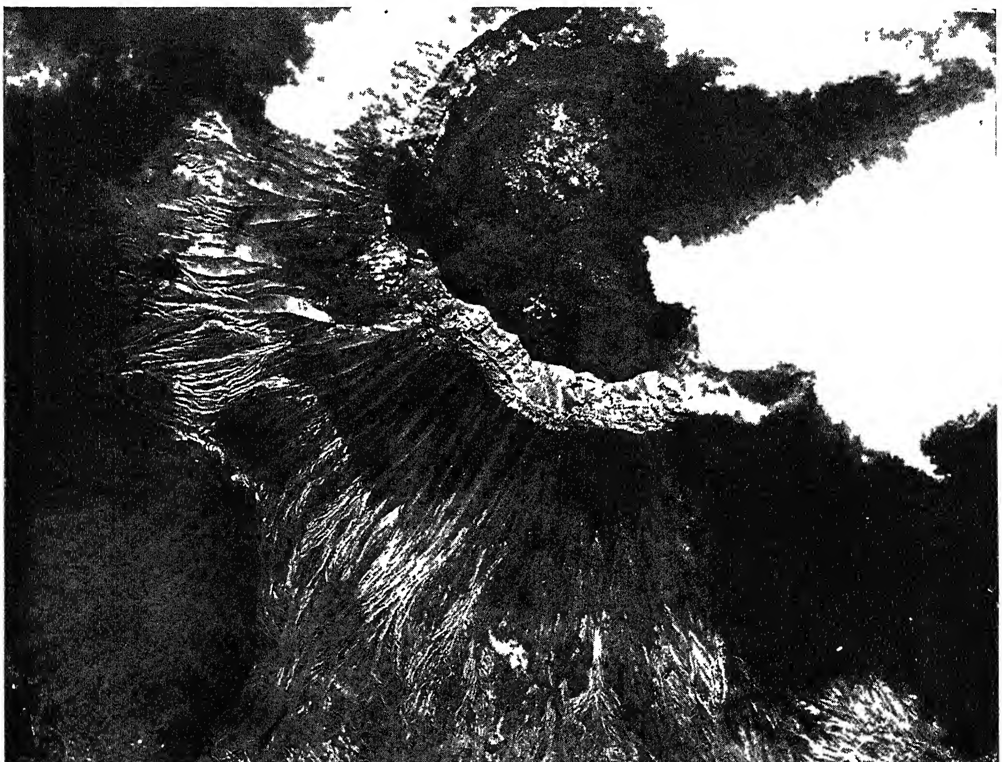
Photo International Newsreel

AIRPLANE VIEW OF MT. VESUVIUS AND THE BAY OF NAPLES

The top of a volcano usually shows a more or less cup- or basin-shaped depression, called the "crater". The characteristic conical shape of a volcano is un-

doubtedly due to the manner in which the mountain is made. It is merely an accumulation of frozen lava, fragmental rocks and cinders ejected from a hole, and the material thus thrown out naturally assumes the shape of a cone with a funnel or pipe through its center leading to a cup-shaped cavity at its summit. The angle of the cone depends on the viscosity of the lava and the cohesiveness of the material ejected — the more viscous the lava, and the more cohesive the material ejected, the steeper will the cone be. The volcanic cones in the island of Réunion, Indian Ocean, which have been formed from very viscid lava, are about as steep as a thimble, while the volcanic cones of the Hawaiian lands, formed from fluid lava, have very gradual slopes, with bases up to 70 miles and more in diameter.

The composition of the cone of various volcanoes differs — some are composed entirely of cindery and slag-like fragments, others entirely of sheets of lava, and others of a mixture of both The more massive volcanoes are usually built up out of alternate layers of lava-sheets and fragmentary material and volcanic dust; and crossing these layers in various directions there are numerous cracks filled with lava, which are known as "dikes". It may seem difficult to believe that volcanic mountains 15,000 or 20,000 feet high have been built up in this manner layer by layer; but it must not be forgotten that the process may have been going on for many thousands of years.



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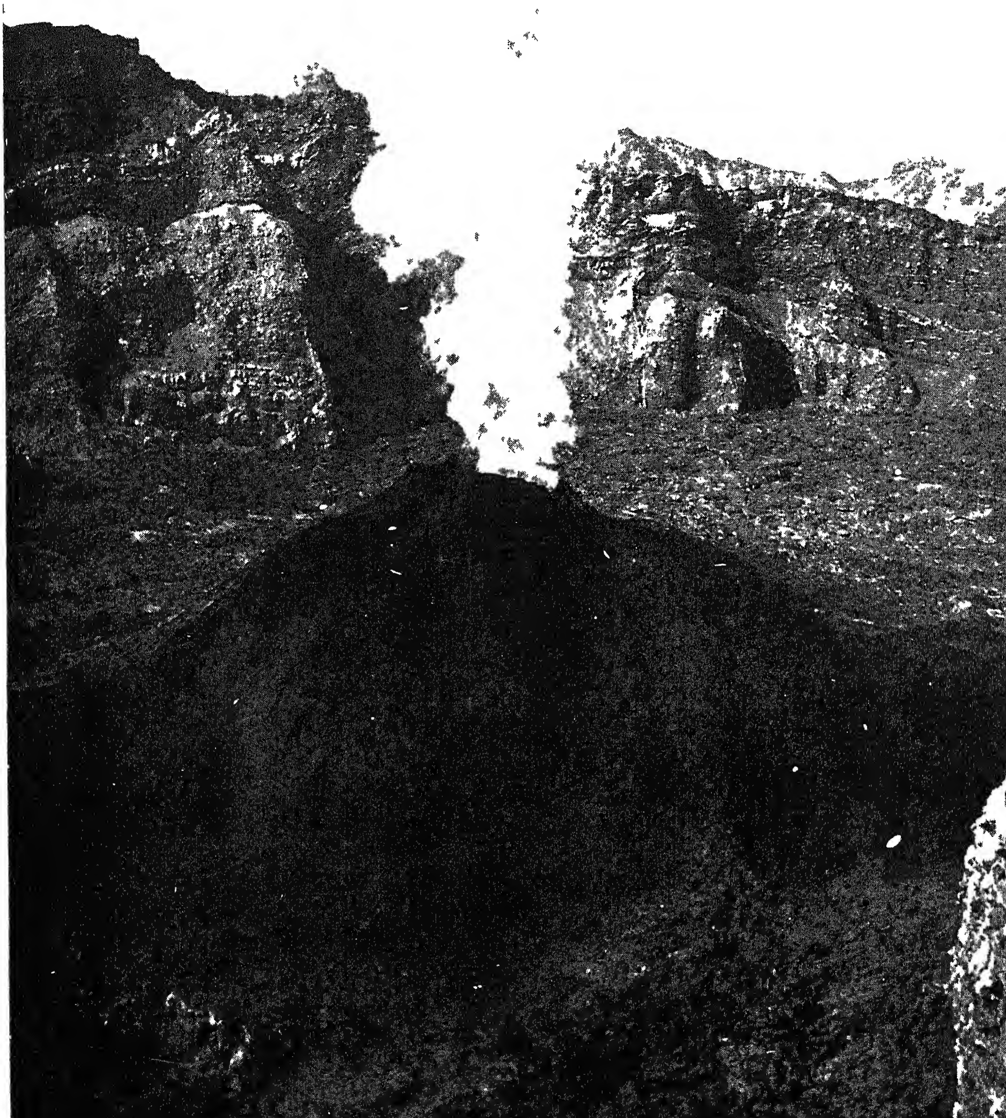
LOOKING DOWN INTO THE CRATER OF VESUVIUS FROM AN AIRPLANE

Mountains made in this way obviously are apt to be broken down as well as built up, and may change their shape considerably in the course of growth. Explosions or lava streams may tear away part of their summits, and in some cases their tops have been blown bodily off. Or new vents and new cones may be formed. During the last century Vesuvius changed its shape several times. In the times of the early Romans, its summit was a great, depressed



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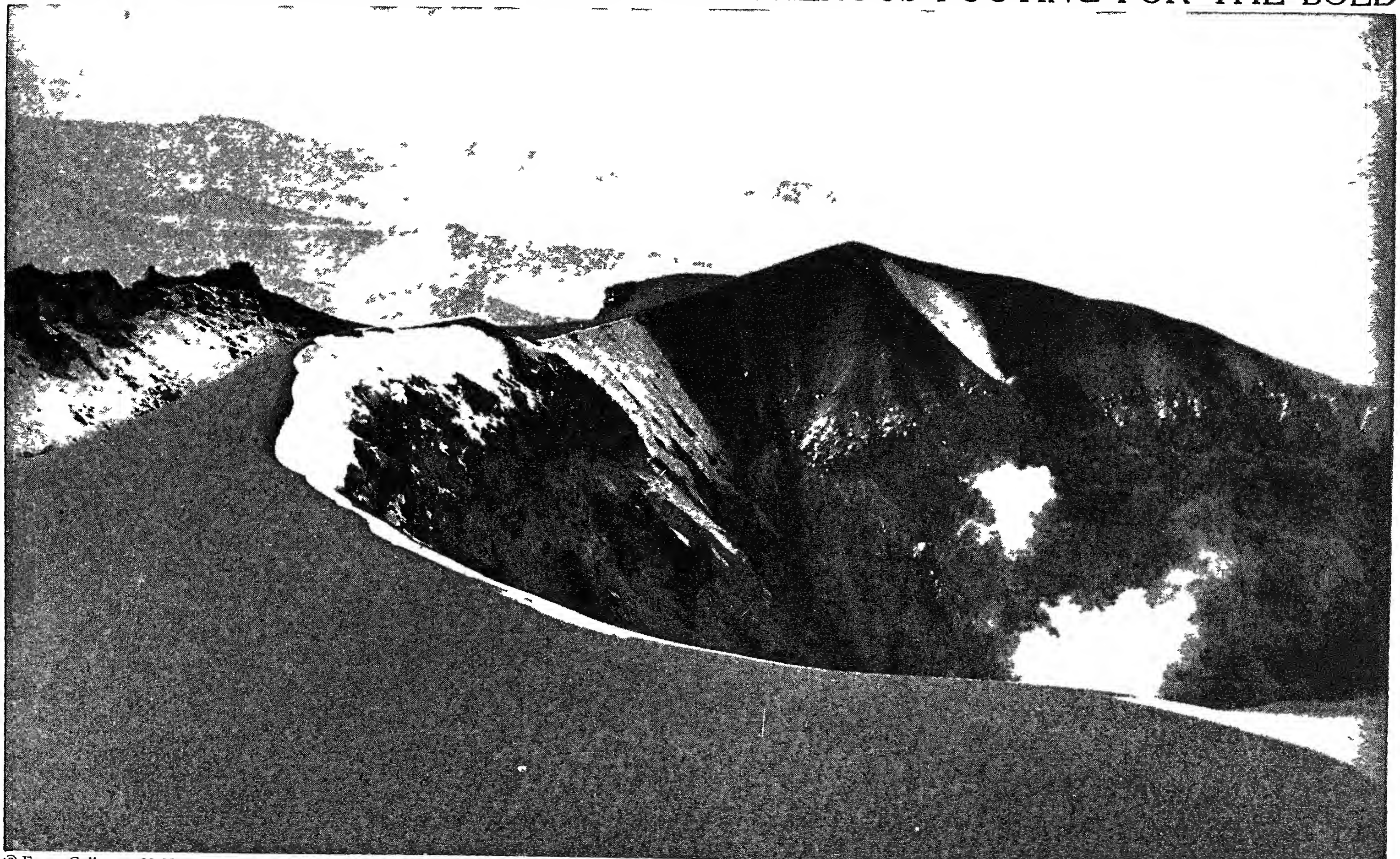
AIRPLANE VIEW OF NEW CONE IN THE CRATER OF VESUVIUS

plain nearly three miles across, where Spartacus the gladiator, with his followers, was besieged by a Roman army After the great eruption of 79 A D it developed a huge crater, and within this crater a new cone with a smaller crater was formed In 1822 a great eruption reduced its height by 400 feet, and produced a huge crater a mile in diameter and 1000 feet deep In 1843 three small cones with craters had sprung up within this crater The eruptions of 1872 and 1906 again changed its shape, and in 1922 a new cone 230 feet high was built within the old crater All active volcanoes are subject to such alterations in shape, but the general effect of activity is to increase the bulk and height of the mountain

Though each volcano begins as a small cone, and is a cone to the end, yet almost all the great volcanoes develop smaller vents which give rise to subsidiary cones Etna has, for instance, hundreds of these secondary or "parasitic" cones, which tend to destroy its primitive conical shape, and the volcanoes of Hawaii have thousands of these parasites In most cases the vent by which matter is ejected is cup-shaped or basin-shaped, and is called a "crater"

THE SNOW-CAPPED FUJIYAMA, JAPAN

WHERE ASHES AND SNOW MAKE TREACHEROUS FOOTING FOR THE BOLD



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THE CRATER OF EL MISTI (19,260 FEET), THE PERUVIAN VOLCANO

A crater twenty miles round on an island in the Pacific

The size of craters varies within very wide limits, and there would seem to be little or no connection between the size of the crater and the height of the volcano. The crater of Orizaba, a mountain 18,250 feet high, is less than 1000 feet in diameter; the crater of Popocatepetl, a mountain 17,887 feet high, is only about twice as large; while the crater of Haleakala, a mountain 10,000 feet high, on one of the Hawaiian islands, has a crater 20 miles in circumference.

Nor does there seem to be much connection between the size of the crater and explosive potentialities, for Krakatoa and Pelée had craters of very moderate size. According to Reclus, the most astonishing and interesting crater in the world is the crater of Kilauea, in the island of Hawaii on the southeast slope of Mauna Loa and twenty miles from its summit. This crater and its action have already been described.

The peaceful lakes that form in the craters of dormant volcanoes

The Spanish word *caldera*, caldron, given first to a very large crater in the Canary Islands, is now used as a generic name for very broad and comparatively shallow craters. These, at least in some cases, have been formed most probably by explosions which blasted off the top of the original cone, thus widening the crater and at the same time diminishing its depth. Many of these calderas are filled with water, forming lakes. The most beautiful and picturesque of these, Crater Lake, is now the center of Crater Lake National Park in southwestern Oregon on the crest of the Cascade Mountains. This lake of pure spring water, twenty square miles in extent and, in places, 2000 feet deep, is 6177 feet above the sea level, and is surrounded by rock walls varying from 500 to 2000 feet high. The Indians called it "the Sea of Silence" and Joaquin Miller has named it "a sea of sapphire set round by a compact circle of the great grizzly rocks of Yosemite".

The activity of volcanoes usually varies greatly from time to time. As a rule, periods of partial or complete inactivity alternate with periods of paroxysmal violence. Until the eruption of 79 A D Vesuvius had been in repose for centuries. The eruption of Krakatoa took place after a slumber of two hundred years; and many volcanoes which seem now moribund or dead may again burst forth into active life. Some volcanoes are constantly active.

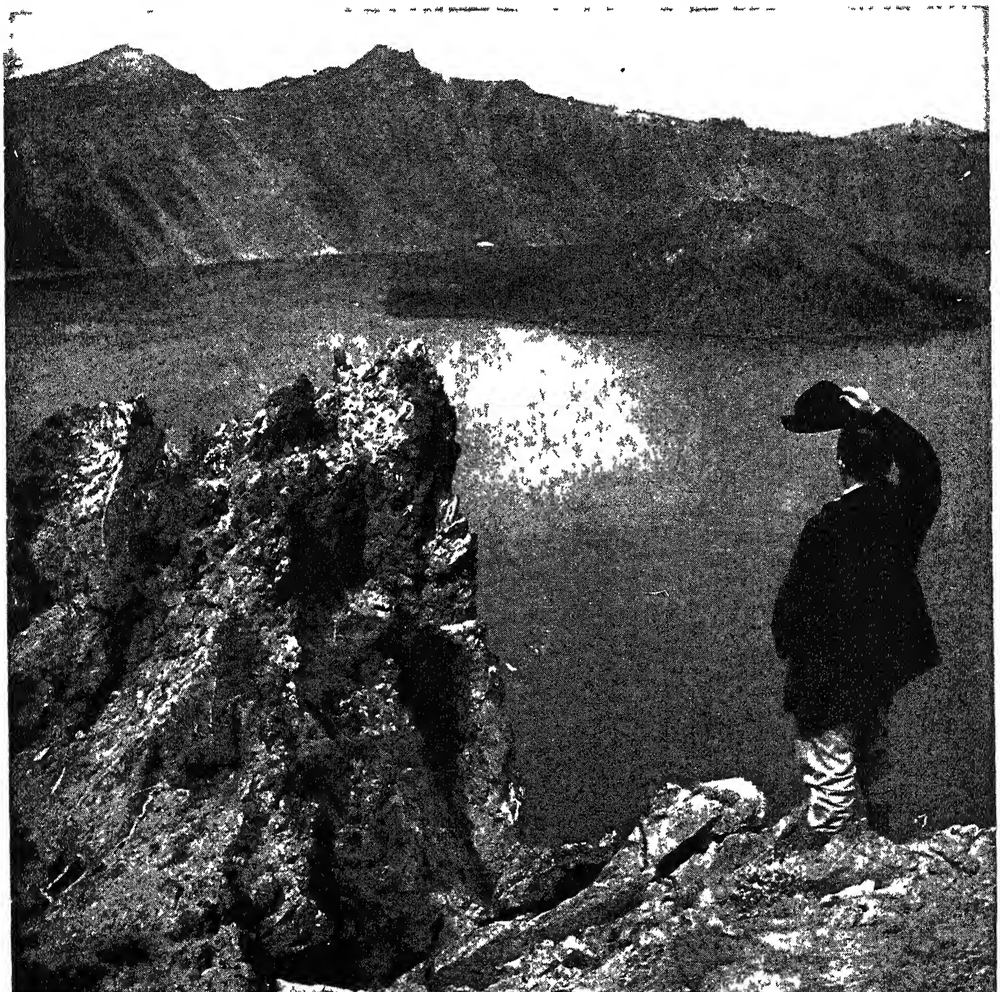
A volcano that has been pouring forth lava for 2000 years

Stromboli has been pouring forth lava for more than two thousand years. Izalco, which was born in 1770, has been in constant eruption ever since. As a rule, the great volcanic eruptions have been those of volcanoes which were dormant for many years; and those that work constantly are comparatively tame. Some, such as the great volcano of Palma, in the Canaries, Mt. Shasta, California, Mt. Hood, Oregon, Mt. Adams, Mt. Baker and Mt Rainier in Washington, seem absolutely dead. Some have been dead so long that the great mountains they built in the days of their activity have been worn down almost to their very foundations. The peaks of some are snow-clad, and their slopes, if not forested, are being so carved and furrowed by eroding agents, that they are fast losing their characteristic shape.

There are several thousand volcanoes on the globe, and about 500 of these are known to be alive. The distribution of volcanoes is interesting. In a general way they are distributed in a linear fashion, and are found along three main lines, which run north and south. One line runs along the ridge which divides the Atlantic Ocean longitudinally into two basins. Along this ridge rise a number of volcanic islands, and on many of these are active volcanoes The island of Jan Mayen has one; Iceland at least thirteen, the Azores six, the Canaries three, the western coast of Africa eight, the West Indies six and there are, besides, three submarine volcanoes in the Atlantic. This line is about 1000 miles in length, and with its branches contains about 50 active volcanoes.

A second line of volcanoes starts near the Behring Straits, and runs all the way down the western coast of North and South America. This line is about 8000 miles in length, and contains about 100 active volcanoes. The third great line also starts at Behring Straits, and runs down in the chain of islands between the Pacific and Indian Oceans. In the peninsula of Kamchatka there are twelve active volcanoes; in the Aleutian Islands, thirty-one; in Alaska, three; in the Kuriles, ten; in Japan (inland to the south), twenty-five; in islands off the southeast of Asia, fifty; in New Guinea, five; in Java, nearly fifty; in New Zealand, three; in the Antarctic region, two All together, this line stretches for 10,000 miles, and, with its branches, includes over 150 active volcanoes.

A fourth line, but not nearly so important as the other three, includes the volcanoes of Mauritius, Réunion, Rodriguez and the eastern coast of Africa. These four lines include almost all the active volcanoes of the world; they all run in proximity to the sea, and the two largest bands form an almost complete circle round the Pacific Ocean. Another point to be noticed with regard to the distribution of volcanoes is that volcano bands usually run parallel with great mountain ranges.



PART OF CRATER LAKE, OREGON

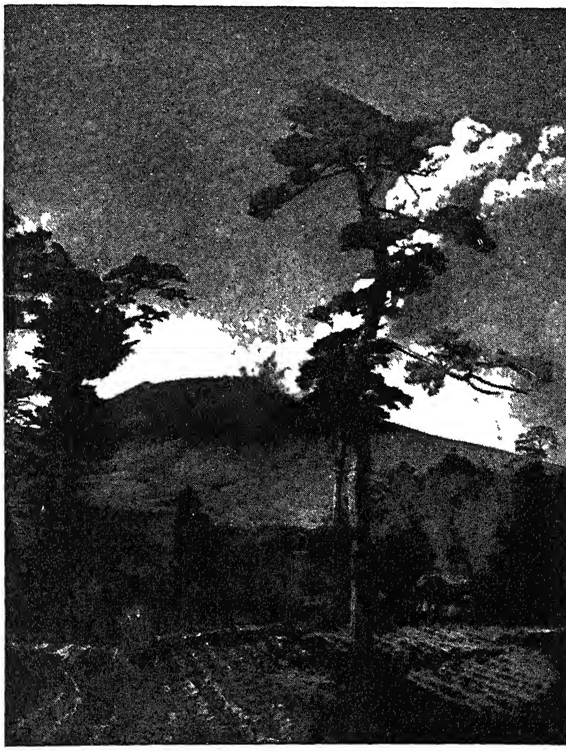
The proximity of volcanoes to the sea has often been explained on the theory that they are due to the ebullition of sea-water which has gained entrance to the hot rocks of the earth through fissures in the crust. The nearness of some volcanic chains to the sea is only relative to the size of the continental masses. The long volcanic line which runs down the west coast of the western hemisphere varies from 30 to 250 miles from the sea and in this line are many active cones, like Cotopaxi, far inland and not near any body of water. Now it is highly improbable that there are any bodies of ground water six miles below the surface, for at that depth there are no fissures and no pores. So the enormous amounts of steam from even small volcanoes in action may naturally be considered a fresh contribution to the existing ocean supply. During a single eruption of Etna nearly 600,000,000 gallons of water were given off as steam, and a small parasitic cone of the same volcano sent out 460,000,000 gallons in 100 days. The main bulk of volcanic gases is steam and all active volcanoes are contributing. The source of the steam emitted during a volcanic eruption is believed to be ground water which has seeped far into the earth and become superheated, and water which was originally present in the rocks when they were formed.

Volcanoes have also pushed out incredibly great masses of solids from the earth. The thousands of extinct and active volcanoes, from small hills to giants of three miles in height (and even six miles like Mauna Kea and other Hawaiian cones measured from the ocean bed), all owe their mass to the earth's interior. The average annual discharge of sediment by the Mississippi is over 560,000,000 tons; Mt. Pelée in a few hours, during the eruptions of 1902, belched out 500 times as much in volcanic dust. These great expulsions of solids leave great depressions. Why shouldn't they, in times gone by, have formed the ocean beds? So, volcanic action, we conclude with some show of reason, may have hollowed the ocean deeps and filled them too. A speculation, of course, with not a very full understanding of the incredible grandeur of natural forces and the time and materials at their disposal.

Photo World Wide Photos

MOUNT ETNA, SICILY

Let us look for a moment at the phenomena of violent volcanic eruptions. Usually there are premonitory symptoms, such as earthquakes, rumblings, sometimes disappearance of a lake, or rise and fall in its levels, or an increase in the activity of the volcano if it be already in action. Then comes the actual paroxysm. Out of the crater rush enormous quantities of steam, mixed usually with small amounts of other gases, and carrying with them stones, rocks, ashes, lava and various other ejecta. The rush of steam is accompanied by a prodigious roaring sound, and the ground shakes and trembles. The column of steam usually goes vertically upwards to a great height, and assumes the form of a pine-tree, to which it was compared by Pliny. In many cases, jets of liquid lava go up with steam, and the friction of the steam against the crater walls creates electricity, so that peals of thunder are heard, and forked lightning flashes to and fro through the column. At times the column is laden with incandescent particles, and occasionally there are gases in it which are set ablaze; and in all cases it is lit up by the glowing lava in the crater, so that it seems on fire. During the worst eruptions the column is so thick and so black that it hides the sun, and makes an impenetrable, pitch darkness. The condensation of the steam causes torrential rain, and muddy rivers flow down the sides of the volcano, and may bury cities, as Herculaneum was buried, at the base.



AN ERUPTION OF ASAMA YUMA, JAPAN

The height to which the column of steam and its contents rise may be tremendous. In 1779, Vesuvius is said to have thrown a volume of cinders and steam to the height of 10,000 feet; and on some occasions its column of vapor was estimated to reach 23,000 to 26,000 feet, while ashes from Krakatoa mounted to a height of seventeen miles. The amount of lava and solid matter ejected varies. In some cases, as in the case of Mont Pelée, the main discharge is steam; in other cases there is a tremendous amount of lava, and in other cases a huge mass of cinders, ashes or pulverized rock. In some ways lava is the most characteristic product of a volcanic eruption, but nevertheless some eruptions produce no lava. In the great outbreak of Mont Pelée no lava was discharged — only prodigious quantities of sand and stones and incandescent dust.

As a rule, however, when the volcano has cleared its throat, lava begins to flow from the crater, or even to spout high into the air like a fountain of molten metal. Usually the lava pours over the edges of the crater, or through fissures in its sides, and when a crater is much fissured it seems to "sweat" lava from numerous pores. Flowing lava is at first white-hot, and steams as it flows. As it cools it grows red and then black. The rate of flow is often at first very rapid, but of course it varies with the viscidity of the lava, and with the slope of the ground. When it reaches a steep place it pours tumultuously over it, while on gentle slopes it may move very slowly. Also, as it cools it becomes more viscid, and runs with greater difficulty.

A stream of lava that was still hot 43 years after it had erupted

The surface appearance of the cooled lava depends on its chemical nature, and on its viscidity when flowing. Viscous, sticky lavas break up, as they cool, into brown or black clinkers or slags, which grate together as the lava continues to flow, and often get piled up into mounds and heaps. More fluid lavas take on a twisted rope-like structure, which Professor Geikie likens to the scum of a sluggish river The heat of lava is very great — in many cases being more than 2000° F. It fuses even flint. It is a bad conductor of heat, and cools very slowly, so that, when it is cool enough at the surface to be walked upon, it may be red-hot below Many remarkable instances can be given of the slowness with which lava cools. In 1830, steam was still issuing from lava which had flowed from Etna forty-three years before.

Jorullo, in Mexico, discharged lava in 1759; twenty-one years later a cigar could be lighted at its fissures, and eighty-seven years later two columns of steam still rose from it. This slow cooling of the lava obviously suggests that the crust of the earth, though cool, may contain molten matter a very short way down.

The vast rocks that are flung far and wide by an active volcano

Besides lava, as we have said, volcanoes discharge huge quantities of rocks, stones, cinders and ashes. It is difficult to get authentic measurements as to the size of the rocks and stones a volcano can hurl, and the distance to which it can throw them. During the eruption of 1779, Vesuvius hurled cinders to a height of 10,000 feet, and in 1815 Tomboro, Sumbawa Island, covered the sea for miles with pumice-stone more than 3 feet deep, so that ships could hardly force their way through it. Among the ashes which buried Pompeii are stones eight pounds in weight. Antuca, in Chili, is said to send stones flying to a distance of 36 miles. Cotopaxi is said to have flung a 200-ton block 9 miles, and Asama, in Japan, according to report, tosses about blocks of stone 40 to 100 feet in diameter.

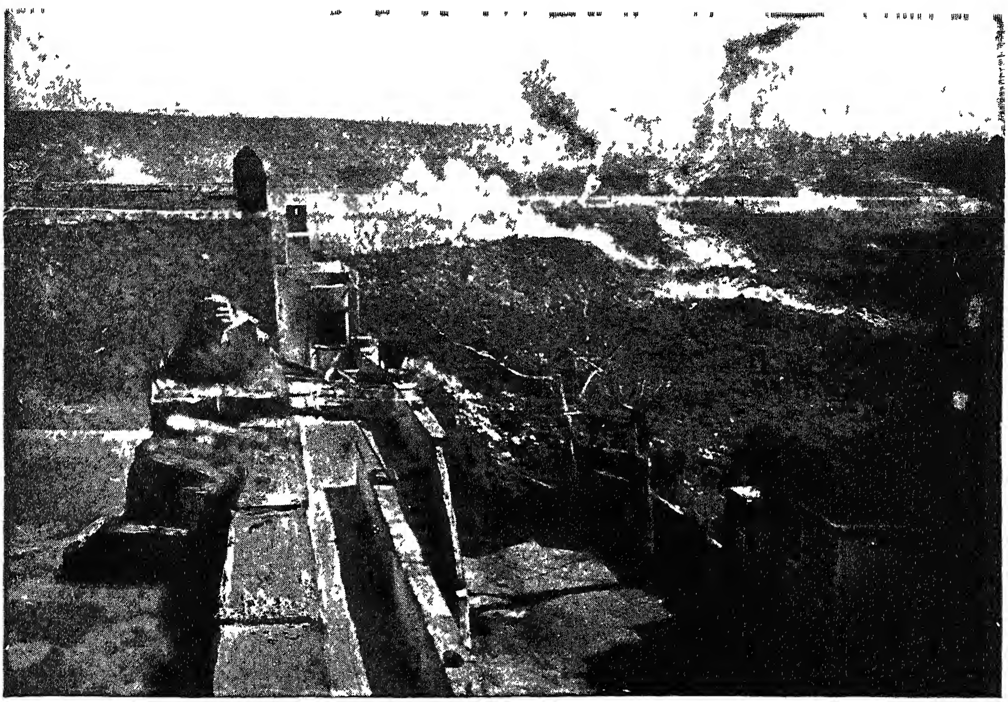
The darkening of the sky and ruin of the soil wrought by volcanic dust

But even more astonishing than all this is the distance the dust belched forth by volcanoes may float, and the great proportion it often bears in the total amount of material ejected by the volcano. When Coseguina, in Nicaragua, blew to pieces, it is computed that 6500 million cubic yards were cast to the winds. The dust was carried at least 800 miles, and sprinkled an area of 1,500,000 square miles. When Tomboro erupted, in 1815, dust fell on the island of Borneo, 870 miles away, in such quantities that the inhabitants still date their years from "the great fall of the ashes". Similarly, after the great eruption of Skaptar Jökull, Ireland, in 1783, ashes fell in such quantities in Caithness, Scotland, — 600 miles away, — as to destroy the crops, and that year is still spoken of by the inhabitants as "the ashie" year. In 1877 the dust from an eruption of Cotopaxi plunged the city of Quito into pitch darkness. The dust from Krakatoa darkened the sky for 150 miles from the mountain, and fell in appreciable quantities 1000 miles away.

The darkness caused by the dust is one of the most trying and terrible features of a volcanic eruption. To be shut into an impenetrable darkness, lit only by lightning flashes and the glow and glare of molten lava, must be an experience to try the stoutest heart. To escape from the night of terror made by the dust of Coseguina, in Nicaragua, men, women and children fled in a body from the mountain, and it is recorded that animals, such as monkeys, serpents and birds, joined the fugitives, "as if they recognized in man a being endowed with intelligence superior to their own". But, strangely enough, this dust, which at first brings on the darkness of night, is ultimately the cause of beautiful and gorgeous skies. Floating in high heaven, and sometimes making several circuits of the globe, the fine volcanic dust refracts and reflects individual colors of the sunlight, and produces surpassingly beautiful sunset and sunrise effects all over the world.

We have already mentioned the torrents of rain and mud that are often accompaniments of a volcanic eruption. Where there is dust, rain soon makes mud, and the deluge of water from the condensed steam soon converts the volcanic dust into a sticky mud that overwhelms and buries all it meets. By such a flood of mud Herculaneum was buried during the eruption of Vesuvius in 79. The great eruption of Cotopaxi, in 1877, covered many villages with a deposit of mud mixed with blocks of lava, ashes, pieces of wood and lumps of ice Whole forests were laid low.

A special class of volcanoes, the submarine volcanoes, must be given a word Etna, Vesuvius, Stromboli and many other volcanoes had their birth under the sea, and no one knows how many active volcanoes may be at work in the ocean depths. Often they throw up cinders and steam, and agitate the surface of the sea. Occasionally they betray their presence in a very sensational way. At times they elevate a new island into the air, and drag an old island down into the sea. St. Michael's, in the Azores, is a favorite place for these emergences and submergences, and on several occasions new islands have come and gone. The Mediterranean, too, is accustomed to islands that appear, and then disappear. In 1831, between Sicily and Africa, a new island called Graham Island, made of lava and cinders, suddenly appeared. It reached a height of 200 feet above water, and attained a circumference of three miles, but it melted away again, and in 1832 no signs of it could be seen. Between Sicily and Greece new islands are often thrown up, but as quickly as they come they go Some islands, however, thrown up by submarine volcanoes, do last. Three islands of the Alaska-Aleutian chain are good examples. The first Bogoslov appeared about 40 miles to the west of Unalaska Islands in 1796, after an eruption In 1883 another eruption about half a mile to the northwest threw up a new volcanic cone of black sand and ashes, known as new Bogoslov, and connected with the elder by a low-lying beach. Another island, called Perry Island, larger than either of the others, made its appearance in the immediate neighborhood in 1906.



LAVA FROM VESUVIUS POURING IRRESISTIBLY OVER A MODERN VILLAGE

Volcanoes are built up out of material pushed out from the earth's crust, but it is not necessary that all ejected material should grow up into cone mountains. In some instances, in the case of what are known as fissure eruptions, lava flows out of a fissure in the earth's crust, and may cover a large area without the production of anything like a volcano cone. Some of these fissure eruptions have taken place on a huge scale, and have covered enormous areas with lava.

The vast seas of lava that flooded parts of India and North America

In Iceland such fissure eruptions have been common. In 1783 two streams of lava issued from a twenty-mile fissure, and flooded respectively 40 and 28 miles. Another stream of lava 60 miles long flowed from a fissure in prehistoric days; and the great lava-desert of Odahahraun, which covers an area of about 1700 square miles, is also a product of a fissure. In the northeast of Ireland, there is evidence of great lava leakage in Tertiary times. It has been said that altogether no less than 40,000 square miles in Britain were at one time under a sea of lava which in some places was 3000 feet deep. In Africa large tracts of Abyssinia are covered with fissure lava, but in India and North America the best known examples of fissure outflows are to be found. The Deccan region of western India is covered for over 200,000 square miles with lava, in places 6000 feet deep. In northwestern United States, parts of Washington, Oregon, Idaho, Montana and California, lie under a sea of frozen lava nearly 200,000 square miles in extent and 3000 feet deep.

When we come to consider the causes of volcanic eruptions, we find ourselves largely in the region of conjecture. We have to discover both the source of the molten materials and the mechanism of its ejection.

Theories that have been brought forward to explain eruptions of volcanoes

This investigation depends on our knowledge of the earth's interior and this knowledge is very little indeed. Some geologists are of opinion that the heat necessary for volcanic action is due to the gradual shrinking and compression of the earth yielding to the force of gravity. This would cause a flow of heat outwards and its concentration in particular regions would result in the melting of rocks. Other scientists, since the discovery of radioactivity, attribute the production of heat to the disintegration and breaking down of radioactive materials. However, the prevalent view at the present time is that the needed heat is primal, the interior remnant of heat in a sphere once molten or intensely hot. The old idea of a complete liquid interior is not held now by any geologist of note. But lava requires molten rock; whence does it come? According to some there are already in and below the crust of the earth pockets of lava due to local increase of heat. Others hold that most of the rock is already above its ordinary melting point, but kept solid by the pressure of overlying rock masses. Release of this pressure means production of lava lakes in the earth's crust. The ascension of the molten mass, with its originally absorbed gases, magma as it is called, is produced probably by variations in pressure caused by shifting of the segments into which the earth's crust is broken up. This again is almost pure speculation. Once the magma moves up, its enclosed gases and vapors break out, producing the eruption and its consequences.

Will it ever be possible to control for man's needs the tremendous reservoirs of energy stored in volcanoes and other igneous agencies? Towards the end of 1923 a Chilean corporation advertised for some enterprising wealthy individuals who might wish to buy a quiet tame volcano guaranteed to deliver a few hundred thousand horse power. Our knowledge of what we do not know of the earth's interior makes us very suspicious of the "guarantee". Still, untamable rivers and headlong cataracts have become docile to man's intellect, and, in the not too distant future, it may happen that some transcendent engineering genius will curb the fiery paroxysms of volcanoes and guide them to steady power.

A CITY'S WATER SUPPLY

How Our Great Cities Are Supplied with One of Nature's Most Precious Gifts

THE MODERN SOLUTION OF AN ANCIENT PROBLEM

WATER, more than anything else, fixes the abode of man. That was so even when he thought chiefly about defense in making his home refuge. The camp or fort must have water — preferably a spring that could not be diverted. It is so today. When men pitch a military camp, though but temporarily, their first considerations are those of the primitive man — dryness underfoot and water near by.

Villages were built on brooks, or in the region of wells, and towns grew up on rivers, first to secure water, and then easy transit, and sometimes power. In land where the population is nomadic, or migratory, the variations in water, in the rainfall or the wells, govern the movements of the community. Indeed, man must follow water, or he must arrange that the water shall follow him. During the early stages of his civilization, when the conditions of his life were simple, he went to the water; now, with enormous labor, far-projected foresight, vast capital expense, and marvelous engineering skill, he gathers the rain from a hundred hills beyond the horizon, and distributes it inside the houses of a million people, so that a little child may turn a tap and drink. This is the story of that gathering and dispersal of the waters.

Looked at in detail, as it affects an individual man or a family, the question of amount in water-supply does not appear serious. A great engineer has pointed out that if it were possible to preserve from evaporation as much of the annual rainfall of London as could be caught by an upturned umbrella of full size, the year's accumulation would be enough to last one man for drinking purposes for a year.

So, on the slated roof of a cottage giving an expanse of 500 square feet there would fall in Massachusetts, at the low rate of 40 inches per depth per year, enough rain to provide the family with 30 gallons of water daily, an amount that probably is not exceeded in ordinary cottage life.

Though it may seem easy to collect these and larger quantities of water under rural conditions, the problem becomes greatly intensified when water must be made instantly available to huge and dense populations in cities for industrial and civic as well as domestic purposes.

For instance, the water consumption of New York City, with a population of more than 7,000,000 is far over 900,000,000 gallons a day. These statistics show a per capita consumption that far exceeds that of London. It has been calculated that to supply New York City's daily demand for water requires a stream running day and night, at the rate of two miles an hour, 60 feet wide and 8 feet deep.

In ancient times the problem of water-supply for the great cities was greater because engineering power was less. As one approaches Rome the first signs of its ancient magnificence are observed in the gaunt ruins of mighty aqueducts which here and there bestride the drear Campagna. Nine aqueducts were in use in Rome in the year A.D. 97, and two others were added later. They brought water into the city from distances varying between eleven and sixty-two miles. The greater part of these conduits was underground, but they emerged as they neared the city, and were carried on arches, as illustrated in the impressive ruins of the Aqua Claudia.

Our water system of today in use two thousand years ago

These aqueducts were chiefly constructed of bricks, stone, and concrete, though lead, bronze, and wooden pipes were used for the final distribution of the water to the houses and baths. The engineering was such as to allow of the use of gravitation as the power throughout, though the principle of the siphon was understood, and had been adopted in earlier ages by the Phœnicians. An unusual proportion of the Roman water-supply would be used for their baths, the bath being a sort of central institution in the social life of the city — club, library, restaurant, and place of amusement.

The treatment of the water was curiously similar to ours of today; that is, the supply was sent forward to service reservoirs, and was only finally distributed after it had passed through settling and filtering tanks. The remains of Roman-raised watercourses can be found in various parts of the Empire, the three-tier aqueduct at Nîmes, 160 feet high, known as the Pont du Gard, and the two-tier aqueduct of Segovia in Spain, being the most characteristic examples. The Roman treatment of the subject was typical of the great cities of antiquity; and Athens and Jerusalem still use a remnant of supplies that were probably engineered 2000 years ago.

The unending race between the population of cities and their water-supply

Of all the departments into which public work divides naturally, none perhaps requires so much forethought and protracted expenditure before a remunerative return is made as the provision of a plentiful supply of good water for a great city. The increasing demand for water in a rapidly developing town is extraordinarily swift and inexorable, and there are cities like Chicago that have been forced to enlarge their supply lines many times. No urban community is keeping pace with its public duties if it has not secured a water-supply sufficient to meet the growth of the next twenty years.

One reason for far-reaching preparation is the peculiar variability of rainfall and a consequent liability to destructive drought. On a gathering ground that is quite favorably situated the supply may sink in a dry year to only about 60 per cent of the average supply of fifty years. Another reason is the impossibility of quickening the command of water to meet emergencies — the enterprise of securing a constant volume of water is comparable to a slow siege, deliberately planned, carefully laid out, skilfully timed.

The enormous cost of waterworks makes it imperative that successive additions should only be completed and be brought into use as they are needed, for a city can as little afford to have too much artificially gathered water as to have too little, since it pays for all it gathers, whether it uses it, leaves it, or wastes it. Hence water-supply is a question demanding far-reaching thought; and the operations it entails illustrate the true use of capital perhaps more perfectly than any other municipal or national enterprise. Millions of money have often been sunk, in foresight and faith, before a cent has been received in return.

The taint of the shallow well and the earth-filtered purity of the deep well

The three usual methods of procuring water are by the use of springs or the sinking of wells; by an intake from rivers; or by conveying from afar the waters of lakes, or damming up valleys and so forming artificial lakes or reservoirs in hilly or mountainous districts. Some cities still use the first of these methods, as at Memphis, Tenn., and Peoria, Ill., but, as cities grow, wells are apt to be discarded in favor of rivers or lakes that will furnish less limited amounts of water.

Spring or well water is the ordinary village supply, and is used in a supplementary way in many large towns where there is a regular piped supply of assured purity. One of the duties of the local health authorities in such towns is to search out the surface wells, that are liable to pollution even if not already polluted, and to put them out of use.

A PURE WATER SUPPLY GUSHING FROM ARTESIAN WELLS

Flowing artesian well at San Antonio, Texas. The water is conducted to the surface through about 700 feet of 10-inch pipe and the quantity is sufficient to create a permanent creek of considerable size

Artesian well, 516 feet deep, at Saint Augustine, Florida. It discharges a million gallons a day.

Why the water from deep wells has to be stored under cover

There are of course, on the other hand, many cities, particularly along the Atlantic Coast and throughout the Middle West, where ample quantities of pure water are obtained from deep wells. Thus at Rockford, Ill., about three million gallons a day are taken from wells from 500 to 1500 feet deep. At Memphis, Tenn., 90 wells, 500 feet deep, are connected with a large tunnel nearly a mile long from which the water is lifted by powerful pumps into the distributing system.

Water pumped from deep wells has to be stored in covered reservoirs, as under the light it scums over with a green vegetation, whereas the surface waters gathered from mountains by gravitation into lakes and reservoirs remain free from such growths.

Wells that leap to the surface and are never exhausted

The supreme instance of service from wells is Brooklyn, which receives over twenty million gallons per day, or almost one-tenth of its whole supply, from its wells which penetrate into the water-bearing sands that form so large a part of the south side of Long Island. These are true surface wells drawing on the vast underground body of water that has been collected directly from the rainfall.

Artesian wells, so called from Artois, the old province in northern France known as Artesium, where such wells have long been used, are the upspring of water confined below an impermeable stratum, which, being bored through, gives the water its release, and it rises to find its natural level. The city of Jacksonville, Florida, is supplied with six million gallons and San Antonio, Texas, with twelve million gallons daily from wells of this character. Sometimes the water from such wells rises in a fountain above the ground level and so sometimes it does not reach the surface, but the cost of pumping is always reduced when compared with such deep well pumping as at Rockford, where the water level is a hundred feet below ground.

The likelihood of rivers becoming contaminated below their upper reaches is obvious, but there is an equal certainty that their waters can be purified for drinking. The drinking water of many of the largest cities of this country comes from rivers, and because of the skill and care used in treating the water before it goes to the consumers, the effect of the contamination is eliminated. Pittsburgh is supplied from the Allegheny River; Cincinnati and Louisville from the Ohio; Philadelphia from the Delaware and the Schuylkill rivers; and New Orleans from the Mississippi.

The need of a National Water Board to divide the nation's water-wealth

Waters for human consumption may be divided into those which are impure originally, but are cleansed and made innocuous, and those which have never been impure. Most of the river waters belong in some degree to the former class. First by storage and settlement such waters lose their bacteria largely, and then are made safe for use by filtration. Still, the ideal water-supply is that which has never been impure, and it usually has the further advantage that, descending from hilly regions, it can be stored at a great height in service reservoirs — at such a height, indeed, that, without pumping, the water will flow of itself to the top stories of the highest buildings in a city of varying altitudes.

Undoubtedly a time will come when the great cities of our country will need the use of all the untainted lofty gathering grounds of water, and will be ready to compete for them with a vigorous expenditure of borrowed money. Then authority will have to be called on to make a division. At present there is a sort of promiscuous seizure, regulated only by the municipal purse and some very inadequate laws. What will be needed is a National Water Board apportioning the national water-supplies throughout the country.

Some approach towards this condition of things has already been made under the pressure of circumstances in various states.

The custom of dividing hill-waters among the people towards whom they flow

In New York State in 1905 the demands for water on the part of New York City had become so great, over 300 million gallons a day, that neighboring communities became alarmed lest all the available water in the southeastern part of the state would be appropriated. Already in 1904 Dutchess County had secured legislation prohibiting any outside locality acquiring water rights in that county, and the mere suggestion that the needed water be found in Connecticut roused such protest as to show plainly that citizens of the latter state did not intend to supply drinking water to those in the former, if any law could be found to prevent. The State Water Supply Commission, since succeeded by the State Water Conservation Commission, was created in 1905, to adjudicate the claims of various contending interests in the same waters. Before that, any city or water company, once granted a franchise, could acquire by purchase or condemnation any water, with any accompanying lands, without any regard for either present or future necessities for water that the people in that vicinity might have. The first claimant took the water and later would-be users went without.

The city of Boston has displayed great foresight by forming all of its suburbs with itself into a great metropolitan water district and then tapping rivers large enough so that all of its people will be supplied.

This plan of coöperation and friendly division is bound to be carried out with frequency in the future, and the sooner some national preservation and apportionment of the water-wealth of the hills is made the better. It can only be done by wide areas which contain considerable urban populations, and villages requiring additional outside supply taking joint action and dividing pro rata the cost of storage and main pipe-line distribution, while each area of water-users pays for its own local distribution. Those who wait longest will fare worst.

At present there is no scheme of national conservation, but legislative customs are being established for the dividing up of the hill-waters among the people to whom they would naturally flow. The legislative and legal views of water-gathering have been almost entirely confined hitherto to regulating the amount of water that can be taken from a stream for irrigation, the relative rights of upstream and of downstream riparian owners, and the value of priority claims. But not all the water in a stream may be taken out.

The basin of water that gains more as more is taken

The amount left for the use of those who dwell on the banks of the stream, millowners, manufacturers, and so on, varies according to the industries of the district, one-third of the total flow being the maximum compensation allowance. In any case the regulation of the water sent down the stream, its restriction, if need be, to hours when it can be properly utilized, and the attention given to the releasing of the flow of water from the saturated upper grounds into the beds of the streams that feed the reservoirs, tend to improve and equalize the ordinary supply, so that, beyond the storage of pure water for distant towns, there is an advantage to the people who dwell by the banks of the stream. The flow is improved for practical purposes, not injured, by the works which retain water. A judicious storage gives a more even supply, and less waste. This ought to be so, for from twenty to twenty-five per cent of the outlay on waterworks is spent in providing compensation water.

How the water-wealth of a mountain valley is calculated

When a stretch of lofty and lonely mountainous land is coveted as a gathering ground for the water-supplies of a city the first question to be settled is how much water does it discharge normally into the streams that will fill the projected reservoirs. The calculation is far from simple. A single rain-gauge's record cannot be relied on, for local position has a marked effect on the registration of a rainfall.

Three stages of city water supply: storage, conveyance, distribution

An average should be taken of a number of gauges. Then the rain that falls is not an index, necessarily, to the amount of water that finds its way into the streams which feed the dams. The character of the soil must be considered. From some soils water flows off quickly and is lost in floods. Other soils become saturated like a sponge, and slowly give up their watery stores. Evaporation is swifter and more constant in one place than another. After long drought the earth is only slowly charged with moisture by percolation, though its thirst may be keen. The water-producing power of any locality varies enormously from time to time. Thus, a huge spongy mountain will discharge into the stream at its foot, at one part of the year, in a given period, 1500 times as much water as it will discharge during an equal period at another season. From this immensely variable output an average has to be obtained before the water-wealth awaiting the reservoir-maker can be calculated.

The enterprise of providing a gravitation water-supply to a city divides itself into three stages — the storage, the conveyance, and the distribution of the water. Usually the storage is artificial, but in a few cases it is natural with artificial additions, as in the use of Hemlock Lake by Rochester, N. Y., or Sebago Lake by Portland, Maine.

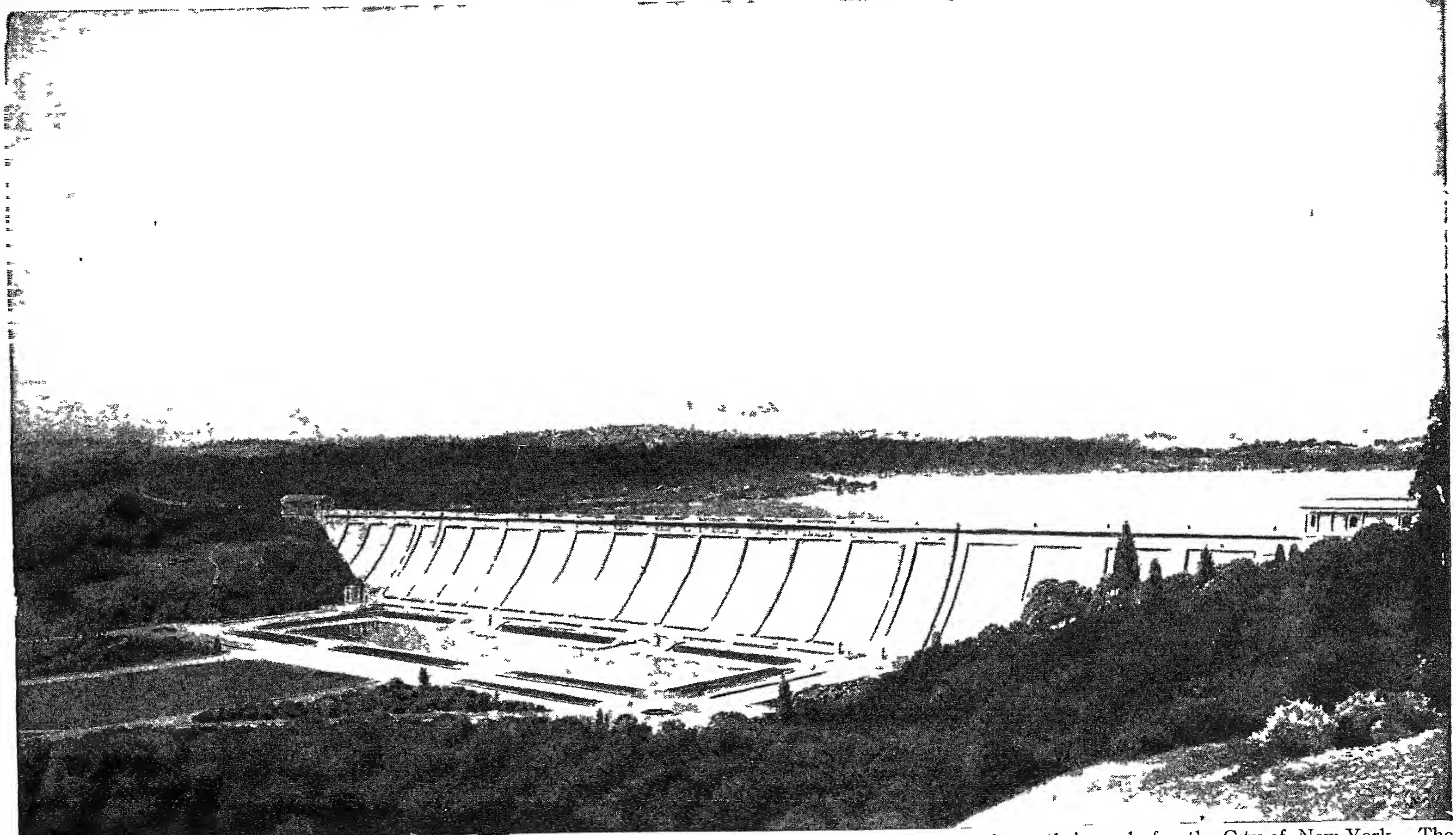
How millions of tons of water are held up safely in the hills

In some cases, as at Skaneateles Lake, which supplies Syracuse, N. Y., the necessary storage had to be gained by building a dam at the outlet of the lake to prevent the spring flood from escaping. The mill owners on the outlet — a score or so of them — had to be bought up, and then the stored water could be gradually paid out as the city needed it. In other cases, as at Sebago Lake, the natural storage is ample. Among the most extensive and comprehensive water-supply systems ever built are those that supply water for Los Angeles, California, with its 2,000,000 inhabitants. The year 1916 saw the completion of the first Los Angeles Aqueduct, which supplies the city with water from the glacier-fed Owens River in the Sierra Nevada, 233 miles away. Water is also brought to Los Angeles by the Metropolitan Water District Aqueduct, completed in the year 1939. It brings water about 300 miles from the Colorado River not only to Los Angeles, but also to a number of other California cities.

Perhaps the chief interest in water-storage enterprise is excited when huge masses of masonry have to be sunk deep into the earth and raised high above it to block valleys and bank in their waters, thus forming artificial lakes or a succession of reservoirs. Dams of this kind are either made with earthen embankments having a central core of puddled clay, or they are made of masonry. Sometimes in old dams earthwork was backed by timber, and there are instances of steel being used. Whether the embankment be of earth or of masonry, a deep trench down to a firm bottom is cut, and is puddled with clay so as to make sure that there will be no percolation through the underlying strata. The bank is then usually built up with concrete in which blocks of stone are thickly embedded, and the wall above water is faced with stone.

The strength of the dam is made commensurate with the anticipated pressure of the water. Thus, the dam of the Vyrnwy Lake, in Wales, supplying Liverpool, holds 12,000 million gallons behind a wall 144 feet from foundation to overflow, across a width of 1172 feet. The wall is 127 feet thick at its base, and its masonry has a weight of 510,000 tons. The area of the lake is 1121 acres. In trying to utilize to the full the waters of the Croton River, the city of New York has built dam after dam for the purpose of storing up every gallon of water that might reach the river and there is probably no other river in the world so completely stored. The first dam, built in 1840, stored up 600 million gallons, but in the spring a good deal of water ran over the dam and was wasted. Since then many other dams, notably the New Croton dam, 297 feet high, storing 32,000 million gallons, have been built.

NEW YORK CITY'S NEW STORAGE RESERVOIR



Kensico Reservoir, with 2200 acres of water surface. This reservoir, costing about $9,000,000, holds several months' supply for the City of New York The maximum depth of water is 155 feet, and the construction of the massive dam has taken five years. The dam is 307 feet high and 235 feet thick at the base

The way to freedom for the rushing storm-waters

A feature of all dams is the provision for overflow, as from time to time enormous amounts of surplus water must pass the containing wall. This is usually arranged for by a waste-weir or by-wash at the end of the wall, the water falling over a series of steps to break its force, before it escapes by the lower course of the stream.

The force of falling water is very great, and even hard rock may be worn away in front of a dam unless precautions are taken to prevent it. The Austin Dam failed in 1900 because the force of the water was sufficient to tear out a part of the dam and move it bodily about 60 feet downstream. Here the whole dam acted as a waste-weir and the shape of the dam was supposed to lead the water away without harm. The necessity for careful design of dams has led some states, as Pennsylvania, to appoint state commissions, which must approve the design before a dam can be built A rule for the safe release of storm-waters is that the sill by which they escape must be fifty feet long for every thousand acres drained.

Failures to observe the scientific principles of stability, or to allow a sufficient overflow, have led in many countries to terrible devastating bursts, especially, though not exclusively, in the case of earthen embankments.

The awful night when the waters washed away the great dam at Johnstown, Pa.

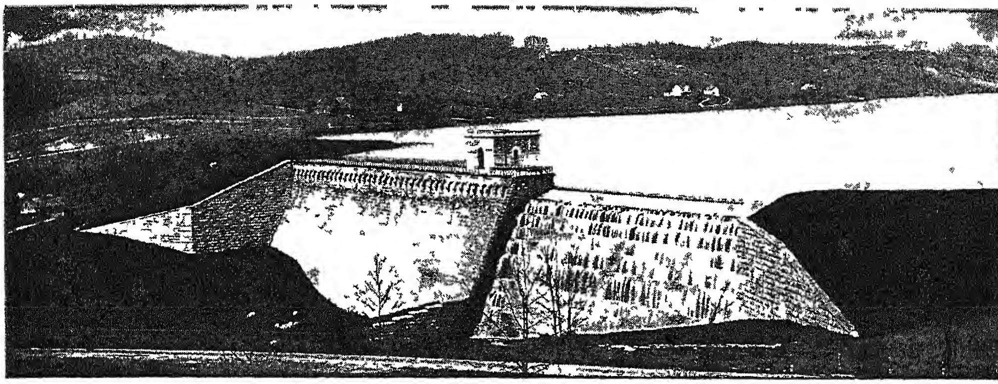
One of the most terrible reservoir disasters of all time occurred in 1889 above Johnstown, Pa , the resulting water-wave being known as the Johnstown Flood. It was a small reservoir, less than a square mile in area, and the dam was a simple earth embankment 70 feet high. The immediate cause of the catastrophe was a rainfall of extraordinary severity which poured water into the reservoir in such a torrent that the waste pipes and the overflow were soon overloaded, and the water, still rising, overtopped the dam and, running down the slope, cut breaches in the bank that emptied the entire reservoir in 45 minutes. Houses, bridges, and trestles in the path of the flood were washed out, finally lodging against a stone railroad bridge in a great raft, which caught fire and burned, adding to the terror and desperation of those who looked on helplessly. There were 2235 lives lost, and property to the value of several million dollars destroyed.

The customary method of drawing off water for consumption is by means of a valve tower. The tower is a dry well built into the reservoir, and carrying in an outer circle pipes controlled by valves through which the water can be drawn off at various levels, and turned into the supply aqueduct The object is to use the purest and clearest water according to the amount which the reservoir contains, and that will be neither the upper nor the lower layers.

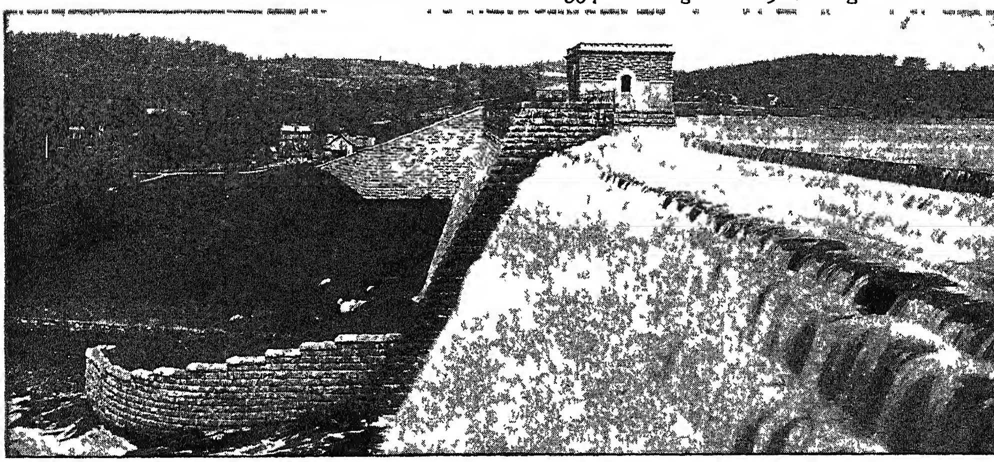
The descent of the water from origin to distributing point

The height of the storage reservoir is a matter of importance. If it is great, the fall to the distant town may be broken by intermediate distribution reservoirs to take off the "head" or pressure on the pipes, and to arrange for distribution to different heights any place that is being served. Thus the waters are let down from reservoir to reservoir, a fresh start being made from each stage, and pressure diminished.

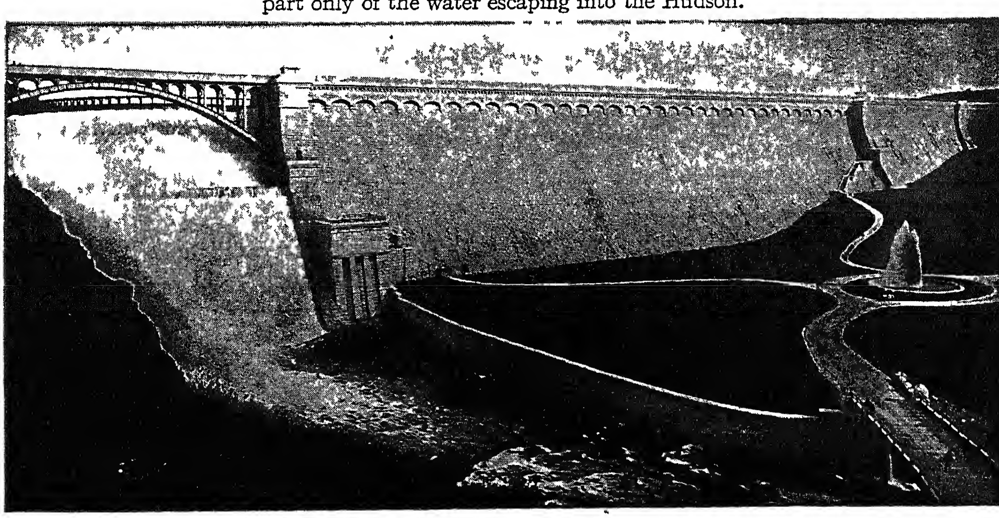
Thus the headwaters of the Owens River, whence the long journey to Los Angeles begins, have an elevation of 3815 feet above sea level, giving a fall of nearly 3000 feet to the distributing reservoirs near the city; 2000 feet of this is within 20 miles of the city, and will be used for developing power, the sale of which it is expected will go a long way towards paying the interest on the bonds of the gigantic enterprise. The Hetch-Hetchy reservoir, completed in 1923, has an elevation of 3500 feet above San Francisco for which it furnishes the water supply. For New York City the Ashokan reservoir has a height of 600 feet, enough to overcome all friction and deliver water to the top floor of houses without pumping.



Titicus Dam and by-wash. This structure forms a small reservoir of 725 acres on one of the west branches of the Croton River. The dam is 334 feet long and 109 feet high.



Spring time flood going over Titicus Dam spillway So completely is the water from the Croton River conserved that the waters passing over the upper dams are caught by lower ones, a very small part only of the water escaping into the Hudson.



The Quaker Bridge or New Croton Dam, built 1892–1906, to hold back the waters of Croton Lake The plans for this dam were studied over for 12 years by dozens of engineers to insure its safety and economy It was the highest dam in America, the top being 297 feet above the foundation.

Nearly all American cities, however, have to pump their water, mammoth machines being used, capable of delivering 10 barrelfuls per second. Not only, then, do these cities receive a pure water, but their gravitation supply can be used effectively at varying heights without expenditure for pumping it up to secure a head.

The water supply of a great city having been stored for consumption, some means must be adopted to clarify, and if needs be, purify it. The presence of swamps on a watershed tends to make the water a reddish yellow color, quite noticeable in a bath-tub. If farmhouses exist near the streams, there is also present the danger of contamination from barns and other outbuildings. There are many cases of epidemics where thousands of cases of typhoid fever have developed in a city through the unheeded pollution of a stream by patients suffering from that disease. Mud or silt in a water is not to be tolerated and for all these reasons some form of purification is generally essential.

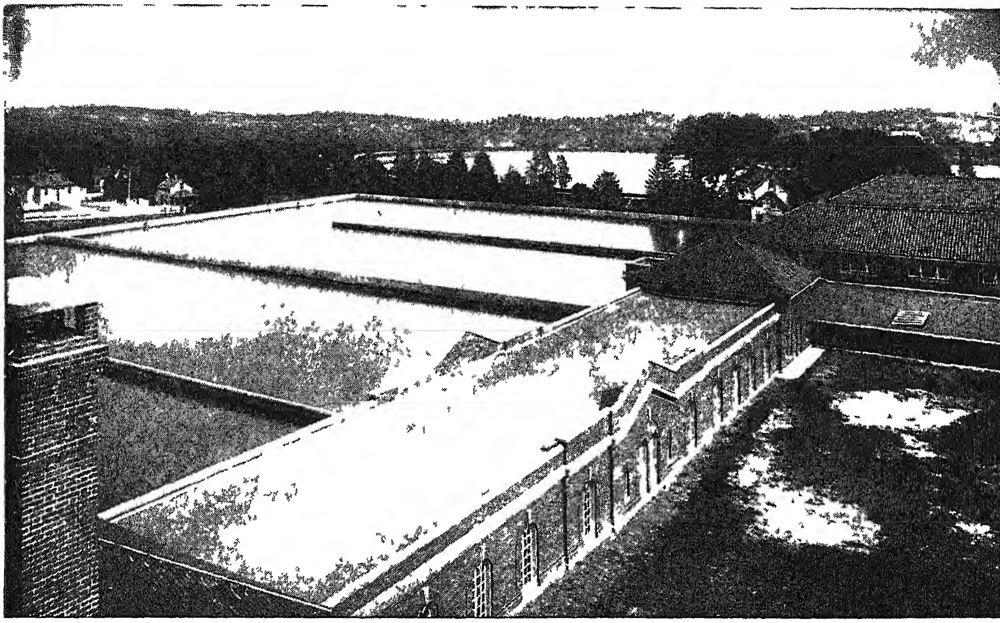
Brown, pure waters that are filtered to look clear

In the cities of the Middle West, particularly those drawing their water from the large rivers like the Ohio, Missouri, and Mississippi, the natural color of the water is a muddy brown or chocolate colored — so much discolored in fact that the very idea of bathing in such a liquid is abhorrent to strangers. In recent years a large number of such river-using cities have installed plants of various kinds to remove the very fine mud responsible for the color. St. Louis at one time treated the water (84 million gallons a day) with chemicals, adding about 400 tons of lime and 12 tons of copperas or vitriol per day. At New Orleans (22 million gallons a day) the chemical treatment is similar, but only 6 tons of lime and 3 tons of iron are used.

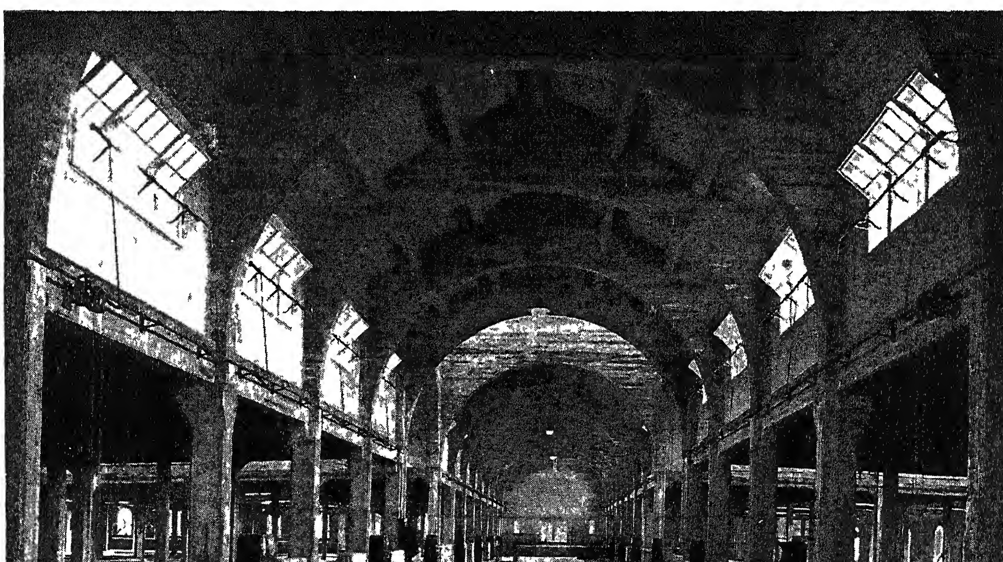
Filtration is now regarded as necessary in the case of all surface water-supplies. In some cases — as with the river water — it is essential to the securing of purity. With the purest mountain streams filtration is advisable in order to combat discoloration, and also because unfiltered water may cause growths on the interior of the iron pipes which carry it on its journey townward, and these growths greatly impede and diminish the flow. The stages of filtration are varied by the condition of the water. Often it is passed through a fine copper gauze strainer of about forty threads to the inch. Then it is allowed to stand, in sedimentation tanks, until its rougher suspended matter has subsided. After this it is drawn, or pumped, off, and passed through the filter-beds. Such a bed consists of a lower layer of coarse stone with finer layers of decreasing sizes above until a thickness is reached that can support several feet of sand.

Bacterial filtration through sand only becomes effective when a film of mud and microbes has been formed on the sand. After a time, however, the sand becomes clogged and impervious, and then a layer of it is removed and washed ready for further use. By a repetition of sand filtration contaminated waters may be made quite pure. In the case of mountain supplies, the filtration process is required rather for the sake of appearance than of purity.

THREE LINES OF 60-INCH CAST-IRON PIPE LAID UNDER THE CHARLES RIVER, CARRYING WATER BETWEEN BOSTON AND CAMBRIDGE



General plan of the Baltimore filter houses, showing the large coagulating basins on the left and Lake Montebello in the background. The filters are inside the long low building.



Interior of one of Baltimore's filter houses. On each side are eight filter units, each 32 feet wide by 54 feet long. Altogether there are 32 filters and the plant can deliver 150 million gallons of pure filtered water per day.

The long journey from the reservoirs in the hills to the water-tap

The conveyance of the water from its source to its destination is often more expensive than its impounding. In the case of the Los Angeles supply from Owens River, the cost of the conduit was 23 million dollars, the distance traversed being 233 miles.

New York City, which talked of going to the Hudson above tidewater 75 miles away, or even to Lake Ontario, 250 miles away, finally has built the Catskill Aqueduct bringing water through a concrete conduit 92 miles long, and capable of carrying enough water for the present population quite independent of the large supply from the Croton River.

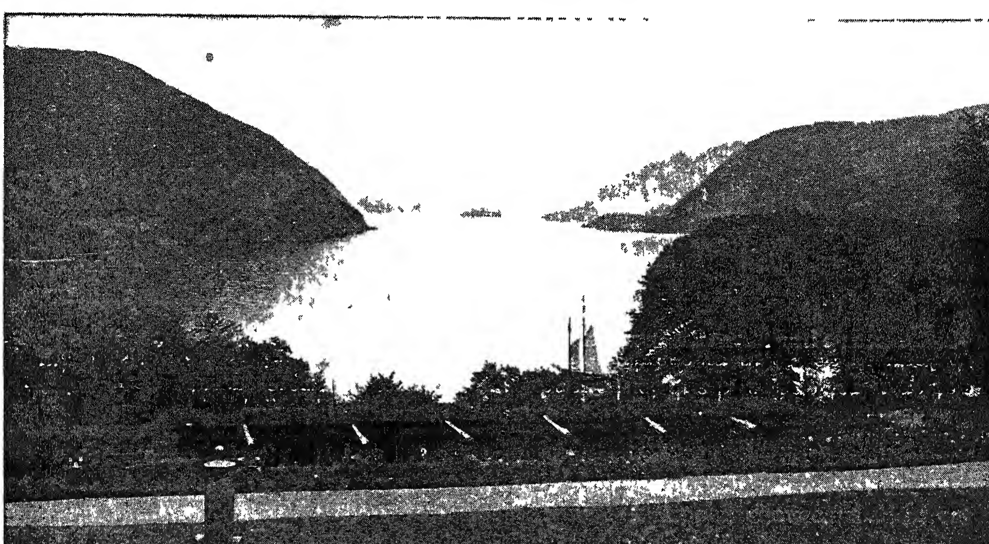
Boston depends on the Nashua River, 30 miles; Washington, on the Potomac, 16 miles; St. Paul, on Rice and Centerville lakes, 20 and 10 miles away.

The aim of the engineers is to make from source to finish — from the water-tower outlet in the gathering reservoir to the distribution reservoir in the city concerned — an underground river with a gentle gradient, along a cement-lined passage, as near the surface as the contour of the country will allow.

Gentle gliding through tunneled hills and switchback piping under valleys

For this purpose a careful survey is made. But often the rise and fall of the surface will not allow a graded river inside the earth to keep just sufficiently below the soil to avoid frost and downward pressure. When there is a rise of intervening hills above the height of the water-line a tunnel must be made. Thus the Catskill Aqueduct has an aggregate length of tunnels of 13½ miles, through which the water for New York flows as if in a channel, the longest single one, known as "Garrison", being 11,000 feet.

Again, where valleys are crossed at a lower level than the water-line, the water must be carried in pipes so as to siphon it down and up again to its former level by natural pressure, and tunneling may be necessary, as, for example, where the Catskill Aqueduct passes under the Hudson beneath the river in a steel pipe 14 feet in diameter at a depth of 1114 feet. Where pressure from a head of water is not required, and the ground will permit, the water is carried in an aqueduct or conduit lined often with concrete, and sometimes reinforced to resist subsidence or weight from above.

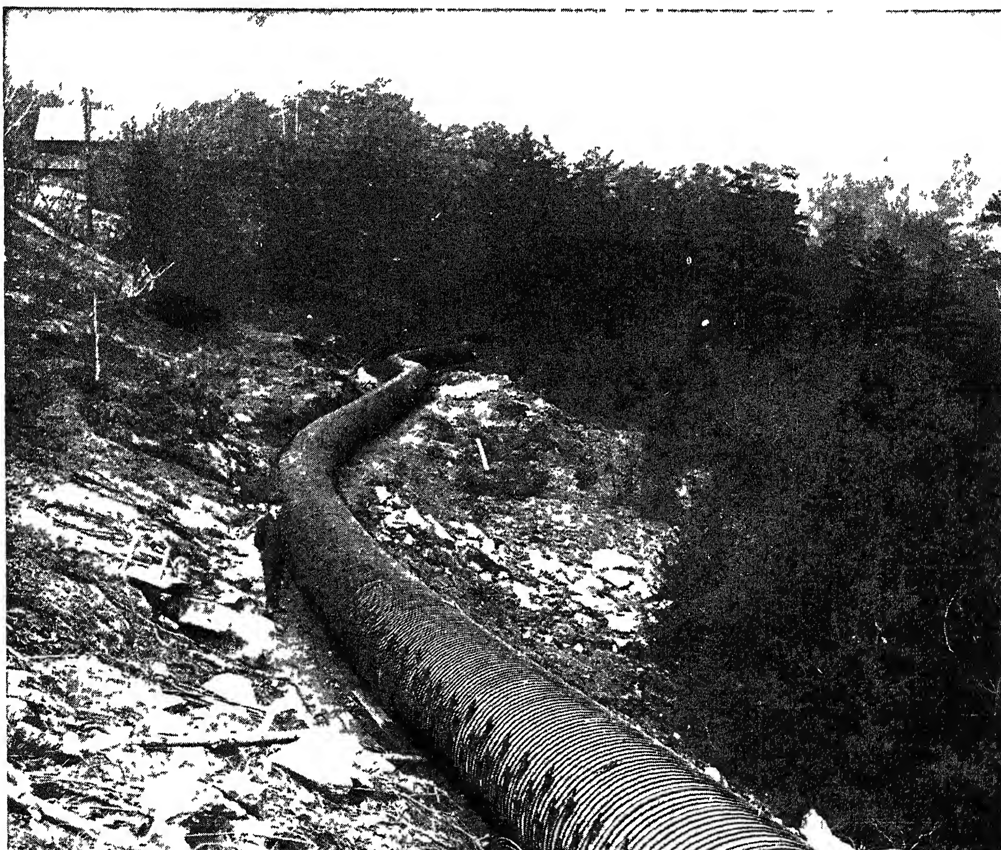


LOOKING UP THE HUDSON RIVER FROM THE HEIGHTS AT WEST POINT

Between the two mountains, the pipe line from the Catskills dips down under the river The steel pipe is strongly concreted into a tunnel cut in the solid rock and, in the middle of the river, is 1114 feet below water.

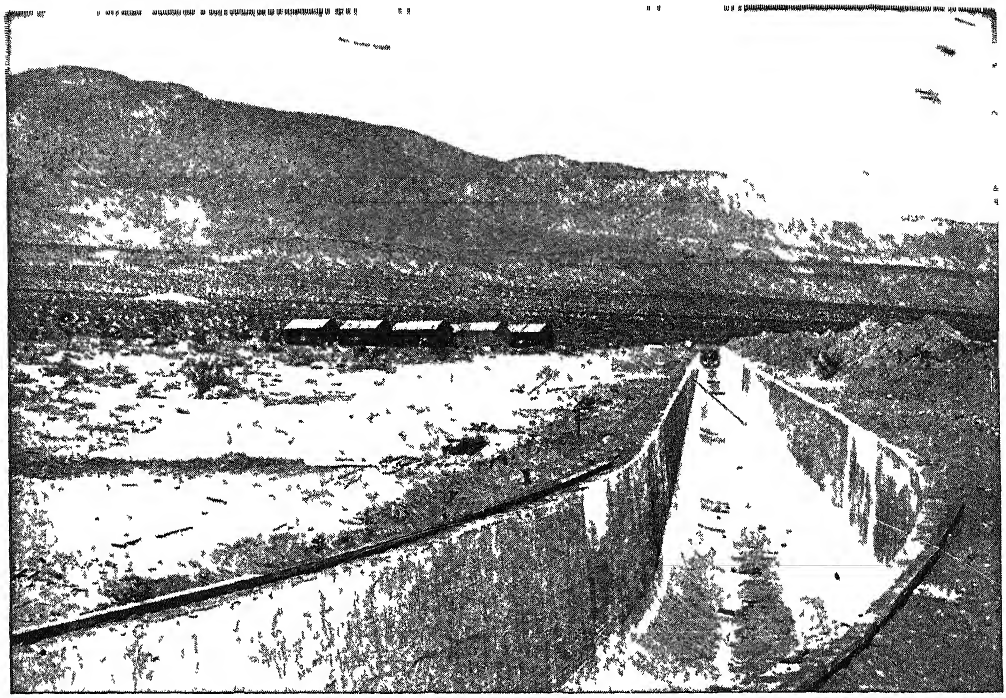
SIMPLE FORMS OF SURFACE CONDUITS

A 48-INCH CAST-IRON PIPE, LAID DIRECTLY ON THE SURFACE



A KIND OF PIPE LINE MUCH USED IN THE UNITED STATES FOR CARRYING WATER

It is made out of wood strengthened by steel bands so that it can withstand as high pressure as cast-iron pipe, over which it has the advantage of being much cheaper.



THE "CUT AND COVER" TYPE

A part of the Los Angeles aqueduct at the beginning of its long reach across the Mohave Desert. The concrete top of the conduit had not been put in place when the picture was taken.

The simplest method of transit is by "cut and cover" and conduit. A trench is cut and a culvert built in it of the necessary size, the top being, because of frost, not less than thirty inches below the surface when the conduit has been finished and the earth again filled in.

Chambers reaching the surface for ingress to the conduits are built at intervals. Where cast-iron pipes are used, there may be from one to four lines and they may be as large as 7 feet in diameter. A 5-foot pipe in Cincinnati burst in 1913, drowning three men, an unusual accident however.

Pipes are dipped in pitch and oil to resist corrosion. Cut-off valves are arranged to stop the flow in case of breaks, and valves are placed in the lower portions of piped depressions to empty the pipes on occasion and remove sediment. Where there is a bend in a pipe-line the pressure is great, and the pipe is "anchored" to keep it firm in its place. The pipes are socketed into each other, and the joints packed with yarn and lead. They carry the water from one "balancing" reservoir or tank to another at a corresponding elevation. Until recently, steel pipe has been used but little because of rapid corrosion. The city of Rochester has such faith in the protective power of an asphaltic coating that they have three lines of 3-foot steel pipe from Hemlock Lake to the city, 27 miles away. Portland, Maine, also has fairly recently built a long line of steel pipe.

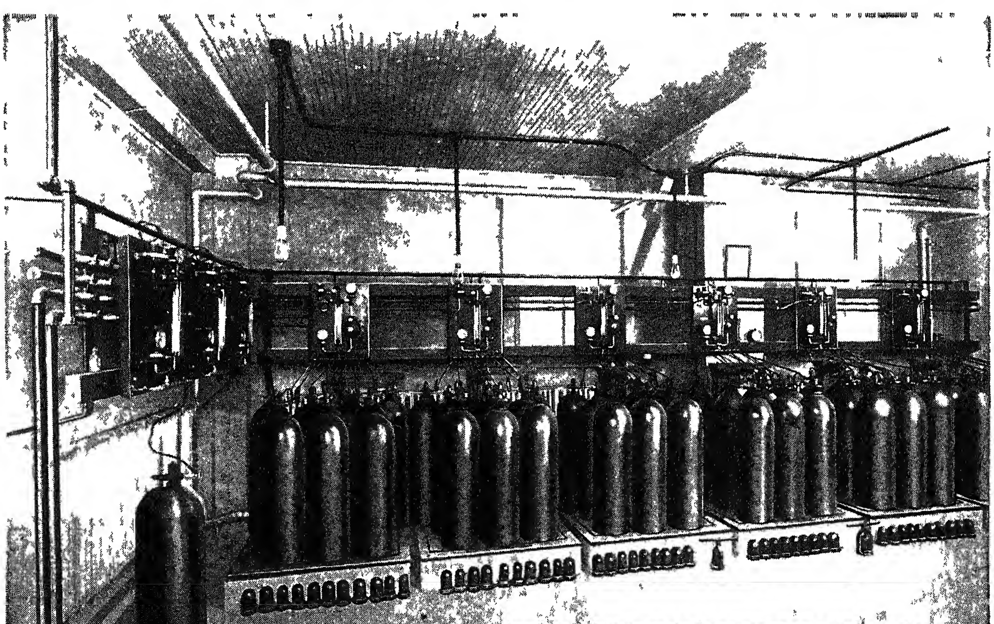
The water conveyed by conduit or pipe, part of the way by one method and part of the way by the other, from reservoir to reservoir, so as to preserve the properly graded fall when it reaches the service reservoirs near its final destination at such a height as will allow it to be distributed to the topmost floors of the highest buildings, is ready to enter at once the mains of the city. Thus Kensico reservoir receives for distribution the New York supply; the Chestnut Hill reservoir the Boston supply; the Cobb's Hill reservoir the Rochester service from Hemlock Lake; San Fernando reservoirs the Los Angeles supply; and Silver Lake reservoir on Staten Island the Catskill water.

Because of the near-by presence of large rivers and lakes, most of the cities of the United States lift their water supply directly from these sources to the distributing reservoirs. Thus Buffalo, Cleveland, Detroit, Milwaukee, and Chicago pump from the great lake lying at their doors. Albany, Philadelphia, Pittsburgh, Cincinnati, and Louisville pump from the great rivers that are continually flowing by them. At first these cities, and others like them, drank the water unpurified and suffered from typhoid fever in consequence. But one after another they have reformed and have installed either filtration or sterilizing plants that are able to change the most polluted water into one of unquestionably good quality. The development of the use of chlorine either as a gas or combined with lime has provided an efficient and cheap sterilizing agent largely utilized.

There is no doubt that a great deal of expensively gathered and distributed water runs to waste. In some American and European cities from 100 to 300 gallons per head per day are expended, chiefly probably in waste. A well-organized system should not show an expenditure of over 60 gallons and probably any expenditure above 75 gallons is waste. Wise prevision by public authorities will enable the demands of the public to be met with amazing cheapness. Though Buffalo, for example, has spent over 10 millions on waterworks, it is furnishing its inhabitants with an abundant supply at less than *two cents per ton.*

It may be taken as an average that the total cost of a great city's water-supply is from twenty to one hundred dollars per head of the population. For this amount the waters from the rain-swept hills, above the abodes of man, are banked up in reservoirs by walls of concrete which sink as deep into the earth as they rise above it, are decanted from their purest layers into cleansing beds of sand, while the surplus stores wash over the embankment and supply the mills downstream.

Now down dale, now up hill, seeking its level, the water is brought on its way, flowing, or by siphon pressure, to a reservoir above the city it serves, and thence is distributed through a meshwork of mains and piping to every house, and in many houses to every room, for instant use.



THE GREAT DUNWOODIE STERILIZATION PLANT

Where all the water from the Catskills for New York City is sterilized Each of the cylinders contains compressed chlorine gas that is allowed to escape slowly into the water where it almost instantly kills all the bacteria present and yet has no effect on the good quality of the water.

Canadian Pacific Railway

Rowing in the artificial lagoon of beautiful and spacious Lafontaine Park, in the city of Montreal.

THE IDEAL MODERN CITY

The Great Common Benefits a Municipality Should Provide, or Insist on, for All of Its Citizens

THINGS WE HAVE OR MAY HAVE SOON

FROM the day when the families of men began to live together for the sake of defense, or for cooperation in hunting or husbandry, the problems of civic government must have existed in elementary forms. The earliest community would have its internal public duties, as well as the external duties of defense, and the securing of the means of subsistence; and at every stage in advancing civilization the growing complexity of these duties would be apparent, until now, wherever we live, the duties, rights, assistances, and restrictions of civic organization hem us in, and, indeed, if we live in cities, become a major part of our lives. Objection to this state of things is entirely useless, for we cannot alter it. Whether we would have it so or not, we are made one family by the cement of the taxes; and the most practical course open to us is to ask how we can perfect that part of our lives which is lived in common with our neighbors. Is it possible to make for ourselves an ideal city? If so, what should its characteristics be?

An ideal city can never be founded on any other bases than the intelligent idealism, foresight and local pride of the citizens. In this respect even piety takes a second place, for knowledge, at present, is broader than piety. "Purify the hearts of your people and the city will be clean" is only a half-truth, for men may be the salt of the earth as far as personal goodness is concerned, and yet, unawares, may be, in some respects, bad citizens. Like Tennyson's village wife, they may attribute the effects of their poisonous sewers to the "will of the Lord".

Given that a city has the power of self-management, and values such power highly, so that all its affairs are matters of keen general interest, and presuming that its best men of business are willing to undertake the administration in a spirit of hearty local pride, then there is no reason why the city should not gradually improve itself into the position of an ideal city, supporting vigorously every institution that is necessary from either a local or a national point of view. What must be the aims that will lead to that end?

Almost without exception, whoever talks about the management of great cities begins with health. The preservation of public health is the subject of the first paragraph in the address of nineteen would-be administrators out of twenty. And very properly so, for health, important in itself, is inextricably interwoven with almost all other subjects of high civic importance, as, for example, with education, housing, recreative exercise, transportation from the crowded districts to the country, and wise and adequate feeding, as well as with formal sanitation. Indeed, half, or more, of the necessities that go to the making of the ideal city might be discussed under the one heading of health.

Now, the first of all desirable things in making the ideal city is space. Unfortunately, it was only late in the day that this fact of prime importance was realized, for in many times and lands other reasons than those of health determined the building of cities. The ruling thought for centuries was defense. The smaller the area to be defended the better, and the houses were crowded on a minimum of ground.

Or, in tropical countries, the narrow street, flanked by tall houses with overhanging roofs, gave welcome shade. Or, again, where earthquakes are not infrequent, and where houses are built, as in Japan, so that they may fall without doing much damage, the building often binds many dwellings firmly together on arches, till they stand in solid blocks which only such a rending quake as that in Yokohama in 1923 can wholly demolish. Each of these reasons for crowding houses on the smallest space and welding them together may be seen in some Italian cities, as, for example, in the older parts of Genoa. It is true that the Romans understood the value of space in building, but the tradition left to modern times by the Middle Ages is one of restriction, and the center of every great European city has an inherited congestion that gives the limited land a tenfold value. Yet, from the point of view of health, the ideal city must have space, both as regards its general plan and its individual houses.

The possibility of every city's approaching the ideal without ruinous cost

So far as the older cities are concerned, central change can only come gradually through improvement schemes, on grounds of expense, the preservation of valuable sites, and respect for traditions; but town-planning arrangements are now possible everywhere in suburban areas; and indirectly they may enormously relieve central congestion, and give business space by drawing off redundant population, always provided there are rapid, ample and cheap means of transit in and out of the city. Under these circumstances, there is no excuse for saying that any attempts to approach the ideal city are impossible. The possibility exists everywhere, and expense is not a bar. The things needed are will power and ideas. As a matter of fact municipal action for the improvement of a city—in proportion to its business possibilities—whether the improvement affects the business center or the suburban residential quarters, is invariably in the long run a paying enterprise. The bogey of cost is only a bogey, if the scheme be well devised in view of local conditions.

Why should not municipal and private enterprise run in friendly competition?

One general consideration deserves mention before we inquire respecting the aims in detail of an ideal city in relation to health, and that is whether municipal schemes of improvement should be positive and formative on the part of a municipality, or be negative and restrictive. In other words, is the new spirit a good spirit when it leads a community to look ahead, to make plans, to welcome ideas, to risk something in experiment, and to say: "We will project improvements that will make some part of this city approach the ideal a quarter of a century ahead"? Or is it better to follow the old plan, and to say: "We will leave improvement to individual enterprise and desire for gain, seeking it only by demanding, through by-laws, a minimum of efficiency. We will say: 'Houses here must conform at least to such and such dimensions, with so much open space, frontage, roadway, etc.,' and thus insure reasonable improvement without risk"?

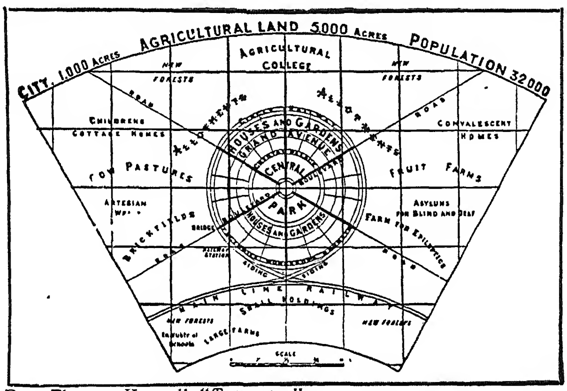
Probably the wisest answer to these questions may be put in the form of another question: Is there any reason why both these methods of improvement should not be adopted? Why should not an intelligently energetic municipality both improve the town, on its own account, and also offer a fair field for private enterprise to show its initiative and successful accomplishment? The competition will be good in any case, and will compel all those who plan and build to give good value, without the burden of extravagant expense. Why cannot a city not only warn the remiss but show the way on its own account?

The ideal plan of an obscure town in the Far West

If we were to select a town plan that most compendiously shows, in outline, what an ideal city should be, we should bring it from quite an unexpected quarter. We should go near the frontier line of Canada, where the Mormons have crossed over from the United States and established one of their communities. There, on the prairie, they have built the town of Sterling.

Roughly, the scheme of it is the scheme of a cart wheel, with the streets converging like the spokes, to a large central open space, like the hub. In the middle of this central part, which is the playing-piece of the town, stands the communal building — town hall, temple, meeting place, concert hall, scene of social gatherings. Every street leads down to the happy playing ground of the children, and across to the center of all social and higher activities. Along the streets passes running water, for the town is a center of irrigation; and the houses are separated, each with its surrounding garden space.

Here, then, we find, evolved by a contemned religious sect, a town that answers fairly to the ideal for playing and pleasure spaces, and also for healthy living spaces around, if not in, the houses; and nowhere in the civilized lands is a fresh start on these lines, on the outskirts of cities, impossible or likely to be unremunerative.



From Ebenezer Howard's "Tomorrow."

DIAGRAM OF AN IMAGINARY GARDEN CITY

Is it not a curious comment on the slowness of mankind, even in these supposedly headlong days, that we have not only failed to decide, save in a few conspicuous instances, what an ideal residential quarter should be like, but we have not even, after a million experiments, constructed the ideal house? Only bit by bit are we learning the essentials of house building, and we do not yet dare to look twenty years ahead. We are speaking, of course, of one or two-family houses. What are the essentials made manifest since the days when the house was regarded as a place where each family could cower in stuffy seclusion?

Houses, ideally, are built to admit an amplitude of air, light and water, and to keep out damp; and they will be built, before long, to admit heat and power. In their building, regard should be given to work, in the kitchen; to rest, in the living-rooms; and to sickness, in one or more of the sleeping-rooms — for sickness will come. Of these needs the most immediate, no doubt, is fresh air, the least understood is light, and the most variedly useful is water, inasmuch as it is the scavenger of the house, as well as the outward cleanser and the quencher of thirst.

It should be impossible in any city to build a house that does not have a daily bath of sunlight, an abundant flushing by a through draught of air, and an ample supply of water for drinking and baths, with sewer connections for refuse. Anything short of this means danger to the community, and an absence of the conditions which make education in health-preservation possible. Health and education, by the way, interlock at many points, and together cover nearly the whole range of social organization.

In this country, where fuel is generally cheap, and the wages of labor also relatively high, we have not yet been forced to appreciate the blessings of adequate warmth in winter. In Europe, especially in continental Europe, the acute pinch of cold is universal among all the poorer people in the cities, and with the progressive exhaustion of our phenomenal resources in coal the problem will become more and more pressing here also. Even now the dread of cold is the cause of much of the evil of our slums, for the cost of heat and the necessity for economizing it is an important motive to overcrowding. The poison of bad air is welcomed by poverty in preference to the cold, and so rooms are hermetically sealed against ventilation. The lure of the saloon was largely its warmth. Now there is no more reason why society should permit homes to be inadequately heated than that it should allow them to be unsanitary in other respects.

Need for a highway for heat and power, as well as light and air, into every house

The piping, or wiring, of the house has now become a necessity as far as water and light (either gas or electricity or both) are concerned, and in most cases for telephonic purposes; and the probability is that the near future will see similar arrangements made not only for the distribution of heat but also of power. In one way or another the next generation will doubtless be familiar with the cheap production and distribution of power on a scale hitherto undreamed of. Not only will workshops and places of business be able to switch on a very cheap supply of mechanical force, but it will be available in every house where a substantial amount of work or cleaning has to be done. What will be needed for men and women will be intelligent direction of mechanical operations, and not muscular exertion. When that time comes, the necessity for packing people into crowded factories will have passed away largely, and cities may spread far and wide in the fresh air, saved from a cramped industrialism, as they have been from the crush demanded in the Middle Ages by self-defense.

The unending duty of caring for the sick and the incapable

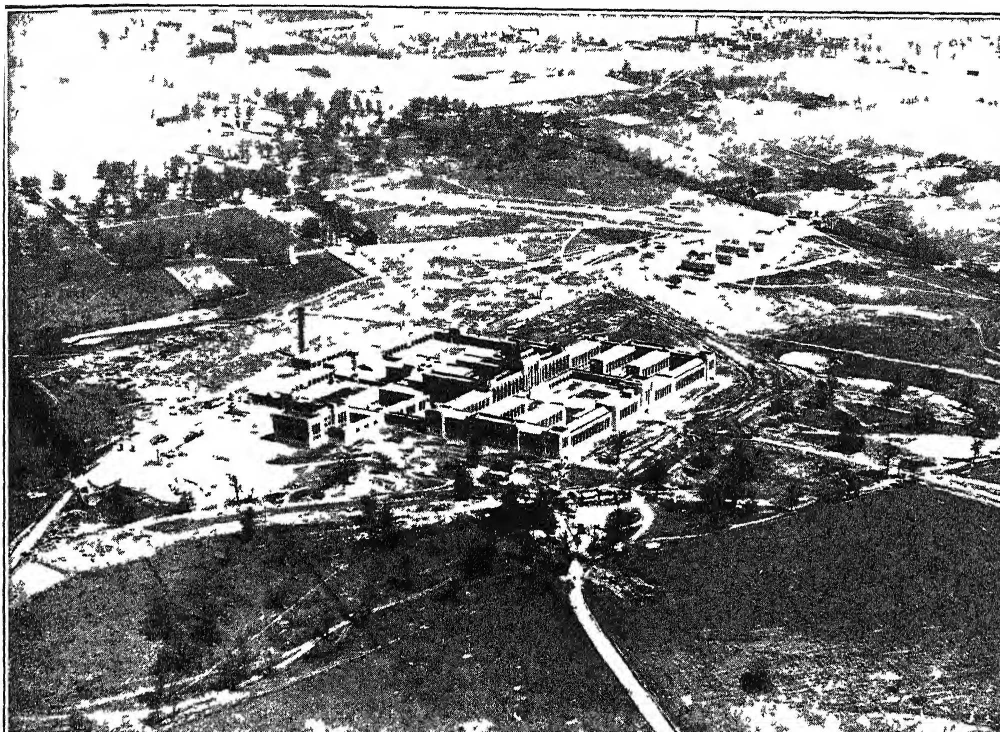
But however healthy the city may be because of its open spaces and its well-planned and fully served houses, there will still be the old need — though in diminishing proportions — for hospital accommodation for the sick and sufferers from accident, and for care on behalf of the weakly and incompetent of all ages, even when cripples have been dealt with by the vocational training experts, and the mentally defective by proper institutions. And this work, in an ideal city, would certainly not be left to the chance impulses of sympathetic contributors. No doubt such benevolence is very fine, as far as it goes, but it is a bulwark for the stingy, who will never pay their share until they are legally compelled.

As long ago as the "Utopia" of Sir Thomas More, spacious hospital accommodation for all sick, with the best medical attention, was demanded, in terms that would be acceptable today; and quite on the same level is the care of the aged whom no pension scheme can touch, and the incompetent, who abound. People who talk without knowledge of the weakness of the poorhouse system generally include in the sum of their ignorance a complete misunderstanding of the main reason why a large proportion of the inmates are "a charge on the public". It is a result of sheer incapacity. These pitiful creatures, perhaps through lack of proper education, training or disease, have never had the opportunity to develop properly. Not one of them in ten can ever have played a man's full part in the world of men. In our ideal city, the sick must be healed — in hospitals, if their sickness is a danger to the rest of the community — and the incompetent must be sympathetically cared for; hence the hospital and something like the poorhouse will stand.

Street-paving in cities as a barometer of health statistics

One of the health conditions of the ideal city is, of course, well-paved streets. This question is usually regarded as affecting primarily the business interest of the city — rapid communication, and so forth — but it is almost equally a matter of sanitation, for the rapid and complete surface drainage of a street, impossible unless the paving is sound, is almost as important as the sewage system for carrying away impurities underneath the ground. The health statistics of any city give an instant response to improvement in street-paving with a drop from a higher to a lower death-rate — a most significant parallelism. The most up-to-date sewage system fails in part if bad paving, or no paving, allows the upper layers of the earth to be saturated with poisons.

After health, and indeed with it in many ways, ranks education in our survey of the demands of an ideal city. An education that never ends is now regarded, happily, as a civic duty accompanying life through every stage. As will be pointed out in our eugenics chapters, it certainly begins before parenthood, in view of the



UNITED STATES PUBLIC HEALTH SERVICE HOSPITAL AT LEXINGTON, KY.
Above is an airplane view of the first Federal farm for narcotic addicts which shows the farm (about 1,050 acres) and buildings, and below is shown one of the structures. This institution, now with 1,450 beds, is for the care and treatment of addict prisoners from Federal penal and correctional institutions, and for narcotic addicts who voluntarily apply for treatment.

coming child-life. Before, at and after motherhood the state already accepts a certain responsibility which it can only make good by giving education in child-rearing. The days of earliest infancy are now days of watchfulness in any great civic community, and the visiting nurse is beginning to be acknowledged as a friend. By the doctoring of sickly infants, by lectures to mothers, by the provision of pure food of a suitable nature, all self-respecting cities are competing for a good record in the preservation of infant life; and the ideal city is bound to be foremost in this most important of cultures.

The public duty of conserving child-life without intermission

We have now solved, to all intents and purposes, the problem of the child who is too young to begin his formal schooling, but not too young to acquire useful habits and skills. The kindergarten, invented by Froebel, guides children through this formative period of their lives, strengthening their bodies, introducing them to the arts and crafts and teaching them the value of co-operation. Another institution that has helped solve the problems of pre-school days is the municipal day nursery, for children whose mothers must go away from home daily in order to earn a livelihood.

We now realize how important it is not to neglect the growing child at any time. The ideal city will never lose sight of its child-life, but will carry out enthusiastically the new idea of education and of the relation of the State to the child, which democracy has given to the world.

What is that new idea? It is not that the State shall assist in the education of the children of Brown, Jones and Robinson, or coerce Brown, Jones and Robinson, if need be, into allowing their children to be more or less schooled, but it is that the whole of the child-life of the nation shall be regarded in the bulk as so much invaluable material to be registered, examined, understood, developed, physically and mentally, and trained most suitably past adolescence. What was a more or less casual parental duty becomes a national task, in which each separate city and town assists.

Making the school a training ground for later life

The great changes in modern conditions, especially the growth of cities themselves, have developed and broadened another gap, at the close of the school period, between the school and life. Educators are making good headway in devising means for smoothing this transition also, and making the school a sort of natural antechamber to the work the child will subsequently take up. The need for changes in the educational system became a necessity when legislation was passed preventing the entry of children into wage-earning occupations before sixteen or eighteen years of age. Professor John Dewey should be particularly mentioned for his great work in devising a system of schooling which, because it interests the child and fits him to enter naturally into a more satisfactory and useful place, will hold him until he is ready to take his place in the social and industrial system.

The full training of all ability, to enrich the national life

The educational ideal of the ideal city must be to give freely to every child, according to its ability, and irrespective of its origin, a full opportunity of developing whatever powers it may be endowed with. Nothing less than that utilization of all the latent forces of national manhood justifies a national scheme of education paid for by all.

There is a growing sentiment amongst teachers in the great state universities in our country that admission should be based upon competitive examinations, and that to place higher education upon a really equalitarian basis, the state should largely support those who are successful in the examinations throughout their university course. Those who lack the power to pass the tests but who would like the adornment of a cultural education might then secure it at privately endowed schools. The generality of the taxpayers would not then be contributing to the schooling of persons who are extremely unlikely to make any return to society for its expendi-

ture. Whatever names may be given to different forms of education — secondary, technical or university — each form of study must be open freely to all who are so gifted that they can take advantage of that form of study, and thereby be prepared to enrich the national life. The motto of the ideal city in education must be — to every scholar his full natural chance. If the facilities for this complete education are not available within a reasonable distance, they should be established.

Since the Great War there has been a remarkable growth in the municipally supported college. Quite often, as in the case of Detroit, the institution is made to embrace the first two academic years, and is called a "Junior College". Such schools may be very economically established by the fuller utilization of higher school buildings. Some of the most notable instances of such schools are those in Cincinnati and Akron.

Outside of school or classroom work of all types, the ideal city will have many agencies and institutions that are educative in their main effects. Lectureships will exist in wide variety, appealing to all kinds of audiences. Museums will suggest and furnish facilities for lines of study; picture-galleries will give and take with other similar galleries, till a broad idea of art in its many manifestations will be presented to the citizens.

Curmudgeon cities that cherish their public pictures for their own sole use

In art, happily, there are few cities that take the curmudgeon view, and try to keep their treasures to themselves, or to set up the absurd claim that the pictures they happen to possess are sufficient for the satisfaction of their citizens' inquiries and tastes. This curmudgeon view is not impossible, perhaps not unnatural, to cities which at great expense have placed themselves far in advance of their neighbors, but civic pride and public spirit generally overcome selfishness.

Some debatable points that arise in the organization of the ideal city are the service of books to free libraries, and the question whether a municipal theater is desirable. In these days of universal cheap fiction, it is generally felt that, apart from the novels which are an inalienable part of the literary history of the country, there is no true need for publicly provided story-telling, and, indeed, that the provision of the novels of the hour is inimical to the study of books of value and novels that have stood the test of time. Indeed, it may be questioned whether in any direction it is a duty of the community to provide mere amusement. Perhaps the dividing line may be most clearly seen in the case of the theater. The drama, which is a genuine study of life and character, and illustrates the actor's art, would take a high place in the scheme of a city's education, but on the same plane there would be no place for the frivolities of the hour that close their influence with an empty laugh. The duty of the community in this respect begins and ends with art — a distinction not always understood, as many a popular municipal program proves.

The civic duty of provision for manly exercises that need space

A whole set of legitimate civic enterprises may be mentioned which belong partly to the department of public health and partly to education. For example, the provision of baths is essential for the teaching of swimming even after every house is provided with a bath and abundance of water and heat. For swimming holds its own both from the points of view of health and of education. Again, parks are a border-line requirement in great cities, called for alike by health and education, and are very inadequately planned if they keep only one of these great aims in sight. The same may be said of all arrangements for drill and athletics — arrangements that might be far more vigorously developed than has been customary in the past. If we examine the commonest of taunts against the townsman of today, it is that he prefers watching games to playing them. But does he? Is not the true explanation to be found in the fact that he has nowhere to play beyond the spaces already fully occupied? In all wise town-planning of the future a look-out must be kept for arenas for physical development.

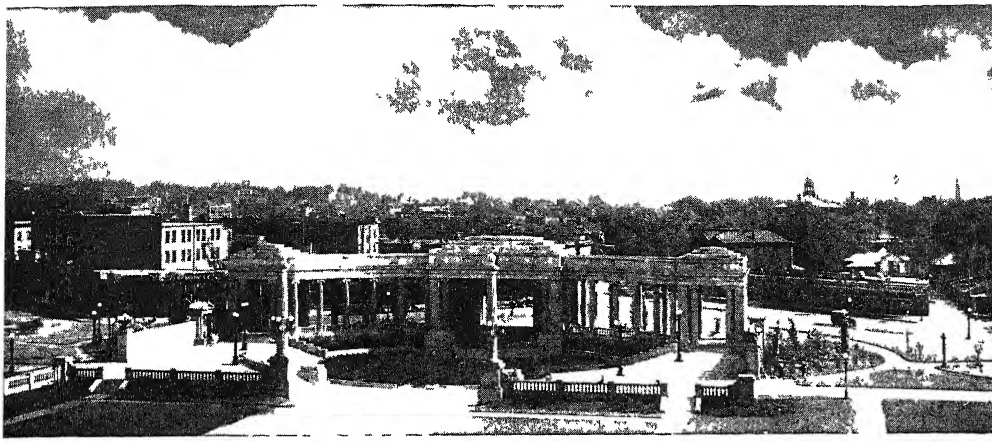
A question that trenches on health and education and taste is: "Would an ideal city provide gardens for cultivation by those who earnestly desire them?" It may be assumed that any such provision would be free of cost to the public funds, for the gardener everywhere is willing to pay the modest price of his pleasure. It may be said that only a small percentage of the inhabitants desire gardens, or would cultivate them in such a way as to make them an attractive sight, and that towards such a minority the rest of the community have no special duty. But is that so? It must be remembered that on the outskirts of a city it is only by municipal action that allotment gardens can be certainly arranged and kept, and even then perhaps not permanently. But any energetic municipal corporation undertaking the full duties of city government will be sure to have land on its hands suitable for allotments — as, for example, land reserved for cemeteries — so that provision of a certain number of gardens is no risk. But behind these considerations lies the fact that many men in cities have a great desire to get back in their leisure to direct touch with the earth's fruitfulness, and take a wistful delight in the production of flowers and vegetables, so that the show from a set of allotment gardens is a sight of exceptional beauty and deep significance. It answers to a healthy primal instinct a city may well preserve.

The extension of public care to the rearing of the nation's children, through every properly equipped office of a Medical Health Officer, has brought organized mankind face to face with the fact that milk is a simple prime necessity for the continuance of the race, and must be provided in a pure form. Indeed, it is being so provided in many a poor quarter, through the public authorities, with an extraordinarily good effect on the health of infants; and the provision of pure milk for all could be readily organized by the city, with much economy in the labor of distribution. In fact, eugenically and economically the milk trade is essentially a branch of the public health department. No other provision of food stands on the same footing, for none is so elementarily simple. There is but one milk to which all tastes must conform, whereas in every other food taste plays an enormous part in the demand, and there is no standardization such as nature herself provides in milk.

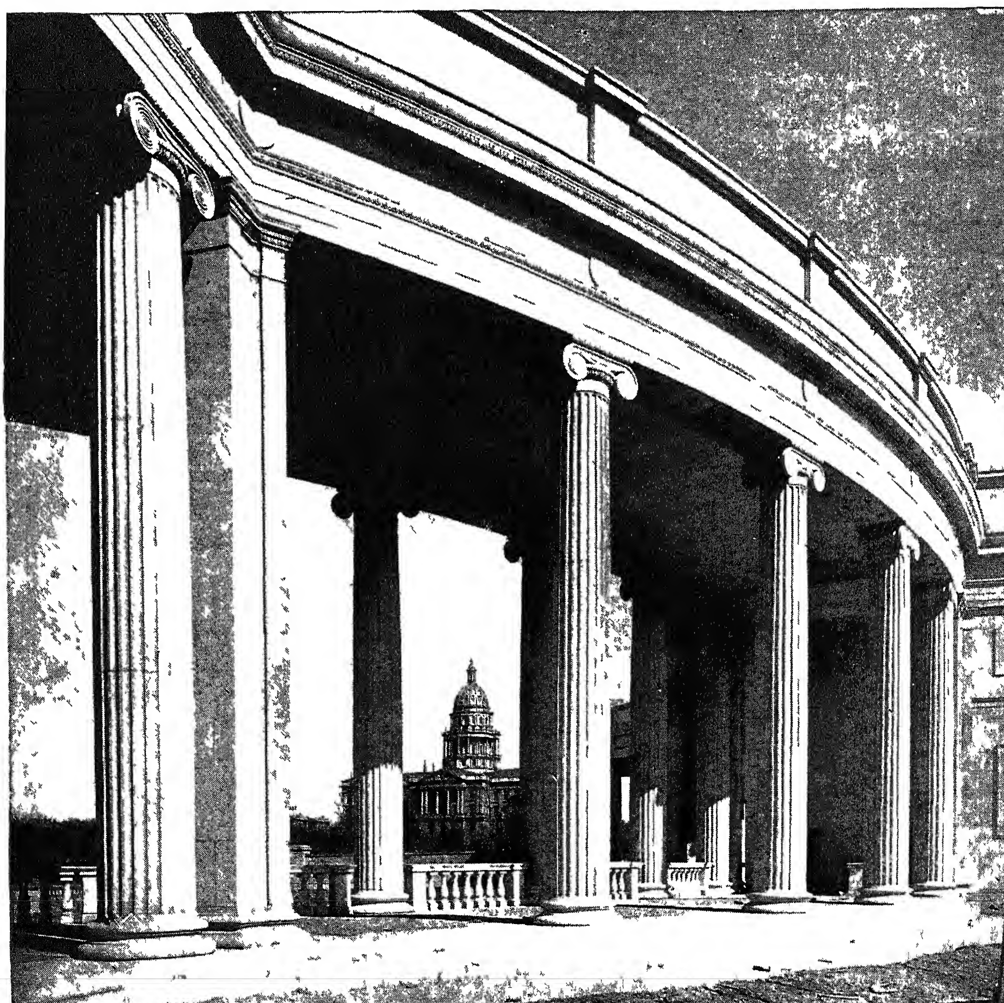
Associated with the food supply is the problem of marketing which has really become acute in recent years. A large proportion of American cities do not so much as own municipal markets, though the privilege of doing so was one of the first possessions of the historic towns, obtained by grant of the English Crown. Though much of the public outcry against "the middleman" is misplaced, there undoubtedly is much waste of foodstuffs and unnecessary increase in price between producer and consumer. Some use of the parcel post system is being made to relieve conditions, and many cities are developing public market facilities. Notable efforts have been undertaken in Washington, in cooperation with the Post-Office Department.

If we search for the real basis of the many joint duties undertaken by municipalities in the name of the citizens on behalf of all, we shall find it in the care of the roads. It was the making and mending of roads that first linked men together in common action, when the need for clustering in self-defense had passed. Tithes were levied for the maintenance of the church, the poor, and the roads and bridges. Apart from religion and philanthropy, then, the road was the first object of communal cooperation, and to the present day it gives the municipality a sort of central hold on enterprises of general utility. Thus the argument for municipalities owning and working the street railways is strengthened by the fact that they are a quicker means of doing what the road was designed to do — namely, to facilitate the passage of citizens from point to point within the area of common government — and it is enforced by the weighty consideration that whoever manages the car-lines must to a large extent control the streets — their making, repairs and traffic. The same argument holds good with respect to all the wires, pipes and mains that pass under the common highway. They should be under the management of the owners

CIVIC CENTER OF COLORADO'S CAPITAL



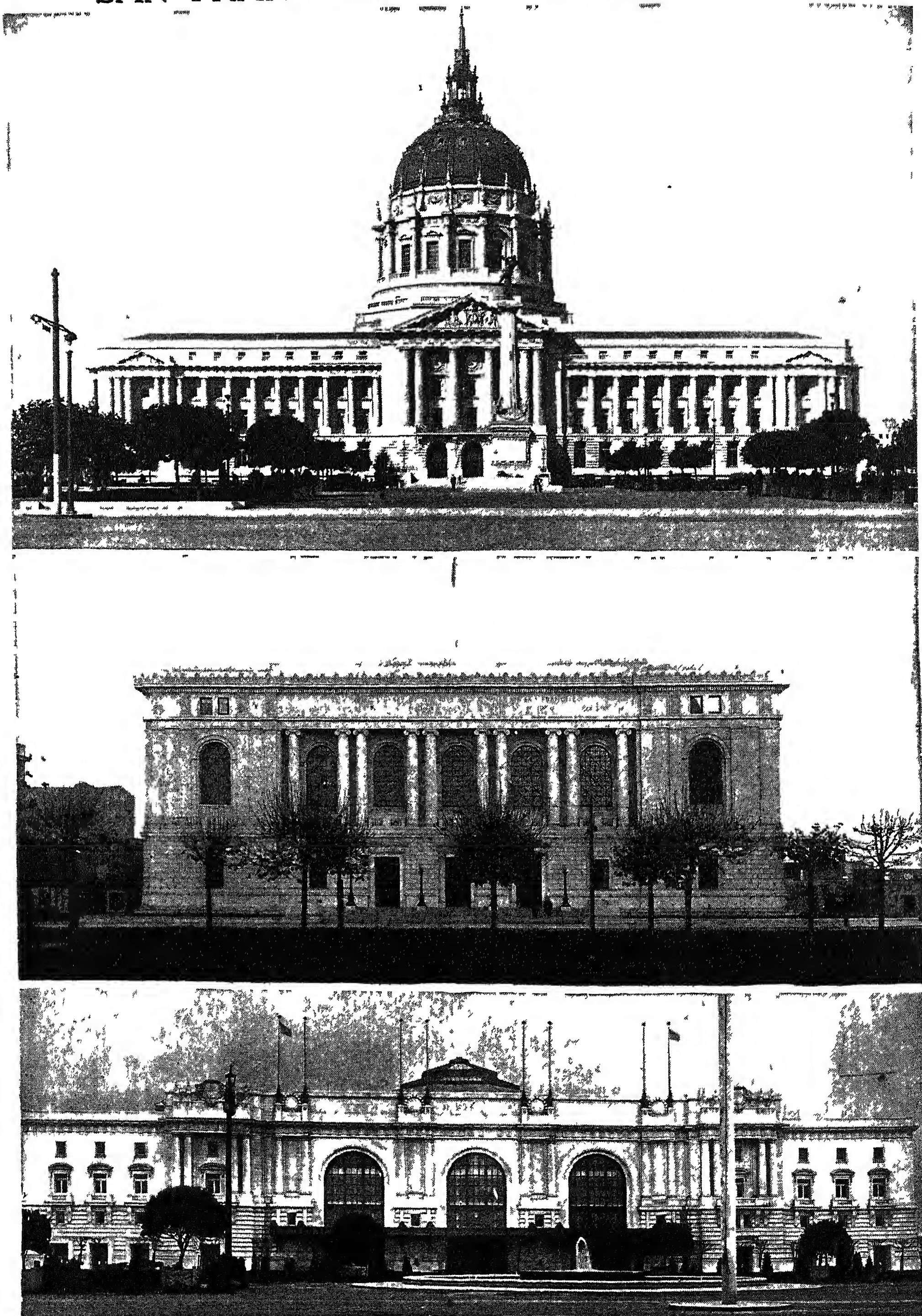
OPEN AIR THEATER AND COLONNADE OF CIVIC BENEFACTORS FROM PUBLIC LIBRARY



Photos L. C. McClure

STATE HOUSE SEEN THROUGH THE COLONNADE OF OPEN AIR THEATER

SAN FRANCISCO'S FINE CIVIC CENTER



Photos by City Engineer

CITY HALL — PUBLIC LIBRARY — AUDITORIUM

of the highway; and the enterprises with which they are concerned may with general advantage be municipally owned as by their very nature they must constitute a monopoly, for competitive opening of highways would be utterly impracticable Competitive business, racing of wheeled vehicles along the surface of such common public roads, is bad enough. The principle underlying sound municipalization seems to be that the community should undertake for itself all those simple, homogeneous enterprises which can be definitely located, as with the bringing of wires and pipes into houses, of the passage of pipes under, or rails over roads

kinds of evil thrive in the dark. Then, too, parks, museums, picture-galleries, and especially a general public use of them under conditions that exact some formality, places them under the guardianship of the public as their property, and tends to set up a high standard of carefulness and attractive behavior. The lessons that are in the air are more potent, as a rule, than the lessons of the schools and of formal moralists

And for that reason one of the most important considerations in the upbuilding of an ideal modern city should be the establishment of a civic center, for social as well as administrative purposes, a town hall to which, sooner or later, every section of the community will be invited, as to a place that is theirs by general right, but that honors them by an invitation. The stimulation given to civic spirit by receptions attended by all types of citizens, the leading business men and city fathers meeting shopkeepers, politicians, charitable society leaders, religious workers, and representative men and women of the rank and file of industry cannot be overestimated. Such gatherings in the common home of the citizens, by invitation, as occasion serves, and with due formality, have effects of a far-reaching character. It is the visible sign of common citizenship, and adds dignity, responsibility and reality to local public life.

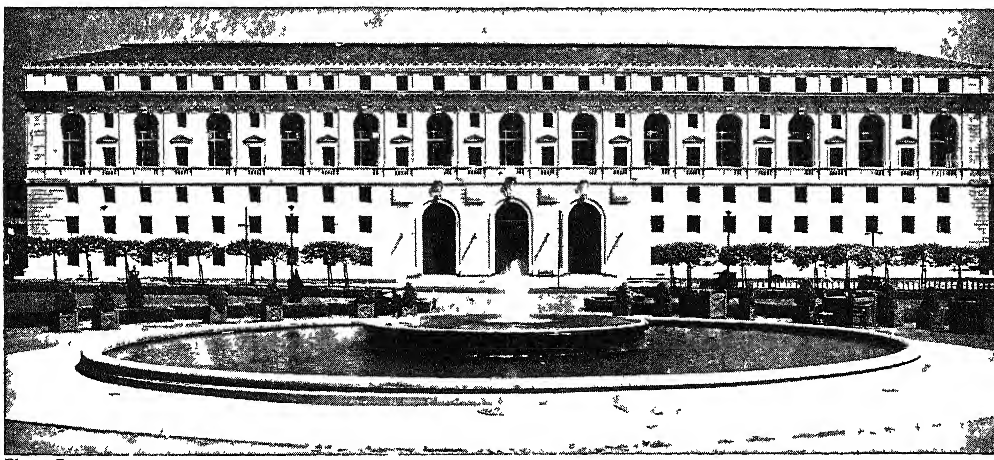


Photo Gabriel Moulin

CALIFORNIA STATE BUILDING
In San Francisco's Civic Center

What has been said so far of the modern ideal city — each feature already realized as practicable in some instances — has been almost entirely of a material character. What about the higher products of human intercourse? In civic government has religion, for example, no formal place? What about the amenities of life, the cultivation of a sense of beauty, the inculcation of pleasing manners? To this objection against the seeming exclusion of the highest concerns it may be urged that the higher influence of a wise material government is far greater than is sometimes imagined. For example, the abundant lighting of a city helps not only in the guardianship of property, but has a distinct effect on morality, and some bearing on manners. All kinds of evil thrive in the dark.

YOUNG WALTER RALEIGH LISTENING ENTHRALLED TO A MARINER'S STORY OF THE NEW WORLD WHICH IN LATER YEARS HE HELPED TO EXPLORE
From the painting by Sir John Everett Millais, in the National Gallery

MEMORY AND ATTENTION

The Art and Secret of Learning

HAVING studied the facts of sensation, and the way in which we associate the impressions that we derive from sensation, we have already had occasion to observe the vital property called memory. A few points, however, need referring to before we proceed to more difficult matters.

First, we must assume that living things do remember. That is, they retain within nervous tissue or in the physiological complex of the living cells impressions of the experiences to which they are subjected in the course of their lives Living things are thus, at any moment, the result of their past physical changes and the sum of their past experiences. We may theorize that in all probability none of a living organism's interactions with its environment (experiences) are completely forgotten.

We should sharply distinguish between the primary fact of memory, which is *retention,* and the secondary fact, depending on the first, which we call *recollection.* We all know quite well that, when we say we "can't remember," we mean that we cannot recall what, in fact, we know to be remembered somewhere within us. We say, "It will come back to me in a minute, though it has slipped my memory for the moment" Obviously, common speech here, as is often the case, confounds two distinct things On further consideration we see that the process of retention and the process of recollection are quite distinct. Each of these two processes deserves some comment, but first we must observe that there is a third process involved in memory, which we call *recognition.* We may retain and recall and then not recognize what, in fact, we remember, such as the face of someone who greets us with the observation, "I'm sure you don't remember me." There the word "remember," very obviously, has more than one meaning

You do remember the face, in the sense that it has been retained in memory, for you know that you have seen the person somewhere before But for the life of you you cannot remember where. In a word, the act of memory that we call recognition has failed. If, however, the person follows up his introduction by a series of hints — "last summer," "at the swimming pool" or "a tennis match," for example — at any moment the act of recognition may follow. Now let us note these three constituents of memory in their natural order.

Retention, the primary fact, is natural to all life, as we have seen, but its intensity varies The degree of retentiveness is probably a unique characteristic of the individual, and will be treated as such. Disease, intoxication, old age or shock may diminish or destroy it It varies also in the course of the individual's life. During the years of adolescence sheer retention is often extraordinarily accurate and easy. The child remembers names, poetry and languages with incredible ease Shortly, however, this acuteness of retention diminishes, and few adults can remember as they did in childhood, if by remembering we mean merely retention. In old age the decadence of the power to retain is sometimes very noticeable. The memory of the remote past remains, because the retentions were made by younger nervous tissue; new retentions, on the other hand, are made with difficulty. Recent facts are, consequently, not remembered, though remote ones, which we might think more difficult to remember, are accurately retained and reproduced Elderly people may recall a great many incidents of their youth.

The most important fact about mere retention-memory, after its universal character, and its indispensableness for all the higher operations and possibilities of the mind, doubtless is that, so far as we can discover, it is what it is, and will be what it will be, except that it can be damaged. It cannot be improved or educated. Education of the right kind will do marvelous things for the memory, but not for this part of the memory. It follows that all "learning by heart" — "To know by heart is not to know," say the wise French — and all schemes and education which assume the value of such rote-learning, must be condemned. Certainly it is necessary to retain, and if these methods increased the power of retention they would be valuable, however worthless the subject-matter, however tiresome the process. The psychological condemnation of these methods depends upon the fact that they do nothing for the retention-memory, while they neglect and often injure the higher parts of the memory, which can be educated.

Value in the subject-matter the only excuse for learning by rote

For all learning by rote, then, two warrants henceforth can alone be admitted. One is that this is a discipline. On that we need say no more than to deplore the existence of those who have no higher and deeper ideas of discipline than the enforcement of what is wearisome, for no worthy end. The second is that the subject-matter of what is taught may have value in itself. Thus, it neither improves the memory nor the reason to learn that "through" and "though" and "trough" are pronounced as they are, but it is useful. What one requires thus to remember, as distinguished from what should properly stay in reference books, until the man who has a really educated memory finds his sure way to it, may therefore be taught by rote and repetition; and even what was not appreciated at the time, like poetry, may be gratefully remembered afterwards. But this purely mechanical method of schooling is not to be called education, and must be sharply limited in its employment.

Impossibility of finding anything in the brain that corresponds to memories

It need hardly be said that to teach by rote requires no qualities on the part of the teacher, and is therefore the natural resort of the idle and incompetent, who may thus readily be identified, where the teacher has any choice at all. Of course, no reference is here made to those who teach as they must, thanks to the demands of red-tape and examinations.

What fact, in terms of nerve-cell and fiber, corresponds to retention, no man can say. No doubt there is some physical fact which corresponds to the psychical fact, but when the physiologist and the microscopist are challenged as to the physical basis of memory they have no answer. The brain of any one of us is somehow the storehouse of a vast variety of memories, of words, experiences, people, things, which were not there once. No one could make sections of such a brain and point to the appearances, under the microscope, which correspond to these memories, and which would not have been there ten or twenty years before.

No observation has distinguished between the speech center of a linguist and that of a peasant whose vocabulary only contains three hundred words, or between the music center of a great conductor who can conduct fifty operas and symphonies without the score, and that of a man who only knows bits of a few tunes, and knows those wrong. Yet, whatever our theory of mind and body, whether we follow Haeckel or Bergson, Lucretius or Plato, we are all agreed that there must be some material difference in the brain which stores memories, as compared with that same brain before they were stored.

The marvelous book of the brain kept in invisible type

The sheer amount of what the brain can retain is staggering. A great linguist or philologist, a great man of science, expert in some department, but with a vision of the whole, a monarch like Napoleon — such people have brains the memory contents of which could not be written out

in years, and which could not be printed, in any visible type, except in a number of volumes which would many times outweigh the whole brain in question, and many times more the gray matter, which alone remembers. If things be "printed" on the brain, the type is ultramicroscopic. We have said we know nothing as to the material basis of memory, but at least we know that the nerve-fibers do not remember, can have no more memory than telephone wires of the conversations they transmit. We are therefore reasonably certain that it is the nerve-cells which remember, and we can say no more.

The total weight of the gray matter of the brain, apart from the blood in it, is a matter of a relatively few grains. True, there are many millions of cells, and when our minds are utterly baffled by the fact of memory, they must try to get what reasonable satisfaction they can out of this huge number. Many cells may be involved, must be involved, in what, for us, is one memory; and each memory of the millions which our brains soon come to contain may correspond to a special combination of an unknown number of cells. But all this is speculation; the fact is that we know nothing, and the more we learn the more we feel forced back to the old view, long scoffed at, of the psychical entity, the soul, which indeed is the seat of memory, and which, in some inconceivable fashion, employs various portions and combinations of the organ we call the brain.

The physical condition of the brain vital for memory

If, on the other hand, we feel inclined to rest in this conclusion, and to let the study of the brain "slide", we must learn how vital for memory is the physical condition of the brain. A mere rough shaking of the brain, producing what is called concussion, may completely obliterate memory; the condition produced by asphyxia, as in drowning, may revive memories thought to be long lost; various intoxications will ruin memory; and in all these cases we can only say that some physical change has taken place, but of its nature no one knows anything.

The second function of memory, which we have called recollection, and the third function, which is the recognition of what is recollected, can be defined in terms of association, as we are already aware, and as is indicated in the process by which a half-remembered stranger restores himself to our recollection. He rouses one association after another until recognition is thereby attained. But the supremely important fact about these two functions of memory is their entire oppositeness to the primary retention in respect of educability. These can be educated, by association, by making many and relevant associations; and therefore, while education is impossible and only disastrous in respect of what rote-learning is designed for, real education is invaluable for its services to these higher functions of memory.

The wonders of associative memory in clever men

There is no mistaking the brain, originally of high quality, in which the associative memory has been properly trained. Its freedom depends upon its chains. In speech or in writing, the possessor of such a memory shows himself at once. It is not necessarily that he remembers names, dates, numbers, like some of the extraordinary persons occasionally seen in theaters, in whom the retention-memory is developed beyond all belief, but who may be nearly imbecile in all essentials. The people of whom we speak may have retention-memories of any class. Their strength is in the chains of association. The mind travels, "quick as thought", "from grave to gay, from lively to severe". The apt illustration, the right quotation — which may or may not be verbally accurate but retains its point, by which it was then and there remembered — the just marshaling of relevant facts, all these are essentially feats of memory.

In times past, retention-memory had its uses, because tradition was the only means of preserving knowledge and achievement. The old man who could retain what he had been taught, and pass it on to his juniors, was necessary for the maintenance and advance of primitive civilization.

Today the arts of writing and printing serve the purposes of retention-memory to perfection, and to regard education as the development of this kind of memory, even if that were possible, is to place man lower than his own inventions.

The right and the wrong methods of utilizing the memory

The object of education is no longer to make a man into a "walking encyclopædia", but (among other things) to make him capable of using an encyclopædia. The great workers and students and thinkers deliberately refrain from the attempt to memorize things. They value their brains and their time far too highly. What lesser people strive to retain for use, these merely know where to find; and the knowledge does not fail them at the right moment, in speech or thought, though the others, who have it all in their heads, may never be able to use it.

This contrast, upon which we cannot too earnestly insist, is never better seen than in the methods of different students, following lecture or book. One will boast that he has gotten down every word, and will then try to memorize the whole. If he is questioned suitably, he can reproduce it all, at examination, like the guide at a show place. If he be asked another question, which requires the associative use of this piece of knowledge, it simply fails him. He has the wrong kind of memory. His is the memory of a talking-machine; he is making himself into a parrot instead of a man, which appears to be the aim of most of our present education. The other student merely listened to the lecture, perhaps with a jotting or two; he may have "read" the book in three hours, where his fellow spent three weeks. But he has gotten hold of the chains, he knows the ropes, and he will pull them when required. That book and its contents are his henceforth, though he owns no copy, and may not refer to it again for a decade. When the need arises, his mind will tell him that he must look up a certain chapter, or will even save him so much trouble as that. And, of course, the man's processes seem magical to the "Victrola", poor fellow.

Misdirected labor of trying to improve retention instead of association

"He who has learned how to learn can learn anything," said Carlyle, who was a great learner, and knew. We see at once what he means. And the reason why this analysis of memory is so necessary, and is being reinforced here with every kind of illustration, is that, in ignorance of psychology, the world of education is full of misdirected labor. National education and self-education, the work in our medical schools and everywhere else, is vitiated right and left by the lack of a clear understanding of the facts of that which we are trying to educate. After leaving school, most of us realize that the time has come for our education to begin, and we look about us for methods and for advice. People are to be found who undertake to improve our memory for the purposes of learning, and we go to their lectures or read their books. But we must distinguish between them, for ourselves, on the basis of the psychological analysis which is here made.

If they try to improve retention, let us have no more to do with them. It cannot be done, nor is it worth doing, except for the purposes of examination by imbeciles in high places. If they try to stamp things into the mind by any process of repetition, however disguised, then we may know that they have not the root of the matter in them.

The indelible engravings made by associative memory without repetitions

The one mechanical fact, so to say, that we know about the elementary, universal fact of retention-memory in living things is that it largely depends on repetition. You hear your own name and write it so often that you are not likely to forget it — "I know it as well as my own name." So with languages or anything else. But associative memory is essentially independent of repetition. In very many instances the association, once made, and never repeated, is there permanently. Most of us have such associations which we would gladly be rid of, but we never will.

The event was never repeated, but the association is engraved indelibly in the memory, and that name, that tune, that odor, that place, will recall something else to the end of our days. Everyone who has had a great teacher can recall the place where he stood and heard his master say some memorable thing, and the name and the place and the saying are associated forever, though never before or since were those words said. Contrast this case with the task of getting up a list of dates, and the only method which will there avail.

Alike for retention, recollection and recognition, there is a factor to which we have not yet referred, but which is of overwhelming importance. We may call it interest, or we may call it attention, and it is both. If we are interested, we attend; and if we attend, and largely in proportion as we attend, we remember. If our interest be intense, our attention is intense, and the memory will be more durable. The literal meaning of the word "interest" is the key to this fundamental fact of psychology. The Latin verb "interesse" means to "be among".

Vital interest the master-secret of true memory

Interest is a vital state of relation to something which *vitally* concerns us, so that *we* are among and within it. Everyone is interested when an automobile threatens to run over him, when his house is on fire or rocks with an earthquake; and we are apt to remember these occasions. The deepest nature of a human being is thus exposed in his interests and memories. The selfish man is interested in and remembers only what concerns him — "A pimple on his nose interests him more than a cancer in his neighbor's mouth", as the writer once heard one of his teachers say. Most of us are more interested in, and will better remember, a scandal next door (which was not true, anyway) than an epidemic or tidal wave or famine that has destroyed millions in China, though we read about it, with languid interest, every day for weeks. Not magnitude, not repetition, but interest dominates; and what shall interest, what we shall feel that we "*are among*", depends on what we ourselves are. It depends on our deepest nature and our experience. You have never been to Copenhagen, and news therefrom scarcely moves you; or you once spent a long holiday there, and everything you can see about it interests you This is clearly a case of interest aroused by association and ultimately depending on interest in the literal sense again; it is *your* Copenhagen, *you* were once there We all know selfish or small-minded people who, in conversation, respond or revert to only those things which interest them, because they have been to the place, they know the author, their aristocratic friend has seen the play and so forth.

Everyone can distinguish, in conversa tion, the man who is interested in himself, and the man who is interested in *us* What associations does his tongue run to!

The will to live roused spontaneously by that which fascinates us

Nothing could be more obvious, more important, more elementary, than this principle. Yet, clear, cogent, universal though the principle be, the greater part of all education flouts it, ignores it, seems deliberately calculated to insult it. We want the boy, the girl, the student, ourselves, to remember; then we must arouse interest. Somehow, their "will to live", their *élan vital*, as Bergson calls it, the thrust of their lives, must be engaged along this line. We may succeed, honestly or dishonestly. The child may care nothing for the subject, but much for the prize We get his interest, and he learns: more shame to all concerned. No child in Japan can work for prizes, for there are no prizes.

Or we are interested because the subject simply fascinates us, and so we learn; or the personality of the teacher or his way of writing is irresistible, and we read what we would never have expected to find ourselves reading. Some strength, kindliness, knowledge, humor, passion, in the author interests us, because these vital qualities serve our lives, thus interesting the deepest thing in us, which is the will to live; and we listen.

Concentration by shutting out the things that do not interest us

We may have heard the same thing a hundred times before, but we have forgotten it; now we remember.

We forgot because our interest was not aroused, our attention was not secured; the deepest *we* of us was not really there at the time. Compare half a dozen people reading the same paper, and all this is illustrated. They all glance down all the columns. One could never tell you that there was anything in them about baseball, or tuberculosis, or the weather; another saw nothing else. The eye at once forgets what it did not want to see.

But we must leave this primary fact, with all it means for teaching and learning, and examine the exact mechanism by which interest works out in attention, and thence in memory. Here we are all indebted to Professor Charles Sherrington, of Oxford, who devoted many years to the physiology of attention in terms of reflex action. His study shows how, despite the incredible complexity of the nervous system, we are able to attend, to be single and devoted, to one thing at a time, to the exclusion of others. It is then, when we are in "rapt attention", based upon vital interest, bodily or mental, that we remember.

Even in a very simple nervous system, and far more in ours, any sensory nerve may carry impulses that run out, so to speak, along any of many motor nerves. Thus, unless some guiding principle be at work, all impulses, coming through eye, ear, skin and so forth, will issue in acts of attention or of motion, all helter-skelter and perhaps contradictory.

Inhibitory action of nervous system giving precedence to main interest

But Professor Sherrington has found, in all the types of nervous system that he has examined, and not least in man's, the existence of what he calls a *common path*, along which sensory impulses must travel before they produce results. And the point is that this common path is like the "party" line of a telephone. One subscriber is talking to someone over the phone. Meanwhile another subscriber on the same "party line" wants to use the phone. The second subscriber will not be able to complete his call as long as the first is on the wire; he will have to wait until the latter finishes his conversation. The first subscriber occupies the common path, and blocks the line for the other. This is exactly what Professor Sherrington has proved to be true of reflexes in general. They inhibit one another, fortunately for us. If one sensory or ingoing impulse gains possession of the common path, the others must wait. He gives a beautiful illustration showing this vital unity of the nervous system in practical working, and the fashion in which what dominates by its interest monopolizes attention, and so makes its impression upon memory.

The brain's impulse to deal with one thing at a time

Suppose two objects simultaneously presented to the eye, but seen not by the center of the retina, but " out of the corner of the eye", as we say. Either of these two objects alone would excite exactly such a reflex action as would swing the eye round so that the light from the object in question would impinge upon the "yellow spot", the most sensitive part of the retina. What, then, happens when two objects simultaneously attempt to gain the individual attention of the eye? If they lie to the right of the field of vision, and in a horizontal line, will the two stimuli be *summated*, as physiologists say, so that the eye swings round nearly twice as far as it should, and thus obtains a good view of neither object? Or will the eye respond to the difference between the two stimuli, with the result that it swings round too far for the clearest vision of the one object and not far enough for the clearest vision of the other? Neither of these undesirable events happens. One impulse or the other gains complete control of the common path, to the entire exclusion of its rival, and the eye is fixed upon whichever object has the most interest in it, and the other is as if it were not there. Try to teach a class of children the exports of Brazil when a fire-engine is dashing past the window!

The theory that attention is an act of the will

We cannot explain attention except with such help as Professor Sherrington affords us, and with some reference to the will. The fact that attention is related to will, subconscious or conscious, is evident to anyone who remembers an occasion when his attention began to wander and was forcibly recalled, as when you are talking to, or being talked to by, a dull person, and find yourself listening to someone else, who is interesting. Professor Wundt, the great German psychologist, has argued that attention is essentially an act of will; and if our view of will is deep enough, and includes the "will to live", which animates the whole of our behavior, we may agree with him. At any rate, the telephone analogy holds good; and the idea of the "party line" illuminates the problem of attention, and the fact of our amazing unity of interest, attention, response and memory, notwithstanding the variety of things that pour in upon us, and the measureless multiplicity of our nervous possibilities of attention and response. When we attend to a voice or a sight, to the exclusion of other things, what is it but the complete possession of the "common path" by the sensory impulses excited by the object in question? In consequence of their control of the common path, these impulses are able to command all the muscles which subserve attention. For it must be remembered that there is a very definite motor or muscular factor in attention; and so much the more do we see it to be a positive act of will, and not something of which we are the passive object.

The absorption possible when a dominating influence commands the nerve tracts

For instance, you are enraptured by a great singer at the end of an opera. In vain part of you says to part of yourself, "You'll be late for your train," nor are you aware of the fact that the man next you is standing on your feet as well as his own. The singer has exclusive use of the common path. And what is the motor aspect of this state of strained attention, as we significantly call it? You cannot cock your ears forward, though the muscles are there and you would use them if you could. But the *tensores tympani* are tightening the drums of your ears, so that they may respond to aërial vibrations with as little loss as possible. Many muscles of the trunk are in contraction, so that your body may be rigid and make no sound. "The audience was held breathless," we say: so eager are you that you even hold your breath. The singer has gained such exclusive possession of the common path that even the reflex action of breathing is interfered with, for a time. Your eyes are fixed, your pupils dilated, and, in extreme cases, muscular tissue behind the eyeballs is excited and pushes them forwards, lest they miss anything. Perhaps the sensory nerves of the spine are also excited, so that you feel "cold shivers down your back", while the secretory nerves of your tear glands may be violently stimulated.

Interest, attention, and memory the highway of learning

Thus complex is the combination of reflex actions which constitute the act of attention in this instance, though the exciting impulse is only single (if you cannot see the stage), or at most double, if you can see and hear. The dominant interest, proceeding from the stage, has gained the common path; all other things cease to exist for the time, are neither noticed then, nor likely to be remembered afterwards. This interest, acting through the common path, ramifies in many different directions, affecting motion, secretion, sensation, through as many different nerves, but all harmoniously and to the one end, expressive of the one interest. These are the occasions we are likely to remember.

Interest, attention, memory is the sequence, and here the teacher and the student must follow the indications of psychology. In such a case as we have quoted, the beauty of the sound, the personality of the singer, the "human interest" of the story, suffice to gain the attention, and the rest follows. But in a thousand everyday cases interest cannot be aroused at first, and the teacher despairs

of getting results. How is he to succeed? The first recourse may be had to the old method of repetition. Even without interest, sheer repetition, acting in some mechanical way, may do something. If the class will not be interested, and learn in that way, it must go over the thing time and again, and learn in that way. But the wiser teacher makes a better choice between the two alternatives which are offered him. The one is repetition, failing interest. The other is to arouse interest, and then all will be well, with little need of repetition, no drudgery, and permanent results.

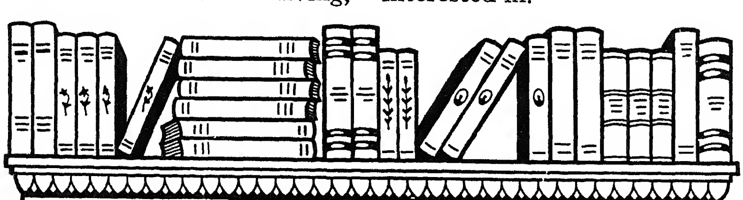
Heartbreaking dullness enlivened by the magic of association

But how arouse interest, where none exists, in a subject which must be dealt with? Only through association can this be done. You must proceed from the already known and interesting to the unknown and uninteresting. Where nothing already exists in the pupil's mind, from which a start may be made, the case is hopeless. Where there are no rational associations, as in the spelling of many words, many dates, irregular verbs, or none which can be discerned except by the expert philologist, or the historian who knows what other events happened and what people were alive in any given decade, there also the case is hopeless. No one should be set to teach such things so. But elsewhere the associations can always be found. That is why the most modern education, here and there, is so promising and delightful.

Where, for instance, science is taught to boys, beginning as Faraday began with his "Chemical History of a Candle", or as anyone may begin with the obvious facts of a boy's own body, interest is aroused and the rest follows, because we proceed from what is already interesting and make chains from it outwards. No man living, no devoted student, no "dry-as-dust" professor, would or could begin in the middle of any science. We must proceed by association from the near and vital, and then all will be vitalized. The dry-as-dust professor is just doing what the reader of the "Sporting Final" is doing — studying what interests him; only he has a long series of associations which we do not see. These are what sustain every student. He may be engaged in the differential chemistry of certain sub-molecules in the group of compounds called "albumins", but he could never begin there, for it would be too heartbreaking and meaningless. He got there by a chain which began with a natural interest in eggs and milk and life and death; and he hopes that, some day, he will find the key to cancer along this line.

A man's worth shown by what he is interested in

Let no mistake be made, the man of science pursues his interests like everyone else. And the moral is that we should treat every student on the same lines. If Newton and Darwin could not study gravitation or variation except by means of an approach, through association, which made these things vital to them, children and all students must be treated as well. Somehow we must make the vital bridge, from daily experience or concern, outwards and onwards, until the child, or the philosopher, finds himself studying and remembering and searching among things which, in themselves, seem destitute of meaning or interest or worth. Thus the secret of self-development is the making of associations from vital things towards vital things, and the extension of our lives, and their creative power, into everything we touch with our minds. And thus we all reveal ourselves. The worth of any man, said Marcus Aurelius, is the worth of the things he is interested in.



SATURN THE MAGNIFICENT

The Story of the Gradual Discovery of Saturn's Retinue — Three Rings and Nine Satellites

A PLANET LESS DENSE THAN WATER

FOR beauty and interest alike there is nothing in the starry heavens to compare with Saturn. This magnificent planet, unique in the solar system for its encircling rings and nine satellites, forms a spectacle that no one can ever forget who has seen it through a powerful telescope. The whole Saturnian system can be seen nearly at one view, and its perfect proportions are very wonderful.

Until the days of Herschel, Saturn was regarded as the outermost of the attendants upon the sun. For the ancients, it was the least of the seven wandering heavenly bodies, as distinguished from the fixed stars — the seven being the sun, moon, Mercury, Venus, Mars, Jupiter and Saturn. The glorious rings that surround it were invisible before the invention of the telescope. Otherwise, this astonishing diadem would surely have saved the planet from the sinister reputation it bore in the days when it was regarded, by the professors of "a sad astrology," as answerable for misfortunes and calamities of every kind and nature.

Doubtless Saturn was chosen from among the planets to bear the blame of bad luck because of its slow movement among the stars, and also because its light is less brilliant than that of any other of the seven. Seen with unaided vision, Saturn appears like a star of the first magnitude, but is excelled in brightness by Mercury, Venus, Mars and Jupiter. This dullness of aspect and lethargy of motion were supposed to impart a gloomy, phlegmatic, saturnine character to those who were so unfortunate as to come into the world when Saturn was in the ascendant.

In the days before telescopes this planet was thought to be the last of the solar system although Uranus, a planet far outside the orbit of Saturn, is clearly though faintly visible by unaided sight. But although the skies had been narrowly scanned for centuries, Uranus escaped detection until Herschel discovered it in the eighteenth century. Pluto was not discovered until 1930, at the Lowell Observatory.

Saturn is so remote from the center of our system that, viewed from its orbit, the sun would appear as a star of enormous brilliancy, rather than as a disc. Saturn is nearly twice as far from the sun as is Jupiter, and receives only one-ninetieth of the heat and light we receive on earth. So remote is Saturn that from its surface none of the planets within its orbit, except Jupiter, would be seen at all, the others being merged in the dazzling brightness of the sun; and Jupiter would appear as a companion to the sun, sometimes an evening and sometimes a morning star, as Venus appears to us.

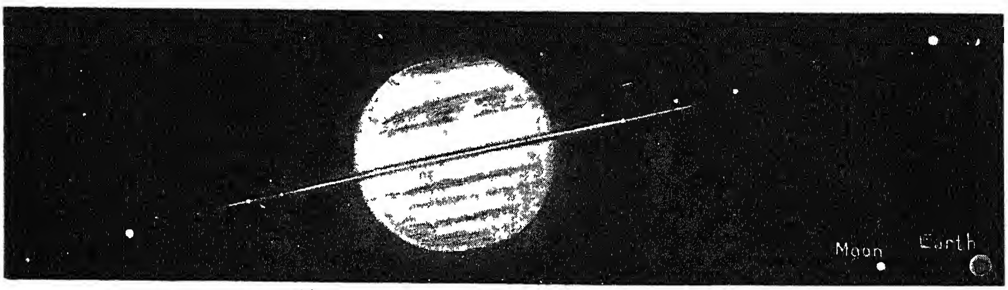
The mean distance of Saturn from the sun is 886,000,000 miles or about nine and a half times the distance of the earth from the sun. It circles round its orbit once in 29½ years, and our earth overtakes it, and comes into line between Saturn and the sun, once in every 378 days, or 13 days over the year. The orbit of Saturn, which is inclined to the ecliptic by two and a half degrees, is slightly more eccentric than that of Jupiter, so that the distance of Saturn from the sun varies to the extent of about 99,000,000 miles.

The distance of Saturn from the earth varies, according to the position of the two

planets in their orbits, from 744,000,000 miles to 1,028,000,000 miles — a variation of distance which is not sufficient to cause any very remarkable difference in the brilliancy of Saturn. At brightest, this planet is not twice as bright as when at its greatest distance from the earth.

The globe of Saturn is greatly flattened, so that, when the planet is in such a position that the plane of its equator passes through the earth, its profile appears notably elliptical — a feature to which much of its gracefulness is due. The diameter through the poles is less by nearly one-tenth than the diameter through the equator, the former, according to Struve's measurements, being about 67,000 miles and the latter about 75,000 miles. These dimensions show the vast size of the planet, whose volume is about seven hundred and fifty times that of the earth, and about three-fifths of that of Jupiter. The superficial area of Saturn is over eighty times that of our globe. But Saturn is so distant from the earth that its vast bulk has an apparent diameter of only from fifteen to twenty seconds.

The density of Saturn is very low, much lower, indeed, than that of any other planet, and even considerably lower than the density of water. With a density of only 72 per cent that of water, it is evident that Saturn is yet far from having reached the solid condition. Like Jupiter, only in an even greater degree, Saturn is still in a more or less sun-like stage of its development and must cool for long ages to come before it can approximate to the condition of our own world. To this molten and perhaps even vaporous condition together with its extremely rapid rotation is due the remarkably flattened shape of Saturn. Its swift revolution on its axis was first observed by Herschel in 1794 by means of cloudy markings visible on the planet which indicated a rotation period of ten hours and sixteen minutes. In 1876 Hall, of Washington, noticed a brilliant white spot on Saturn's equator, and by careful measurements found the equatorial period of rotation to be ten hours and fourteen minutes, two minutes less than the period determined by Herschel. This spot, which appeared to mark a vast eruption of glowing material from the planet's interior, lasted for several weeks, and during that time many astronomers made a close study of the planet's daily motion In 1903 other spots appeared in higher latitudes than those previously observed, and by means of these Barnard and others found the surface to be moving in these latitudes more slowly than at the equator, the period of these spots being ten hours and thirty-eight minutes. This means that a point on the equator is traveling at the tremendous linear velocity of some 23,000 miles per hour, and that there is a relative drift of 800 or 900 miles per hour between the matter at the equator and that in the higher latitudes.



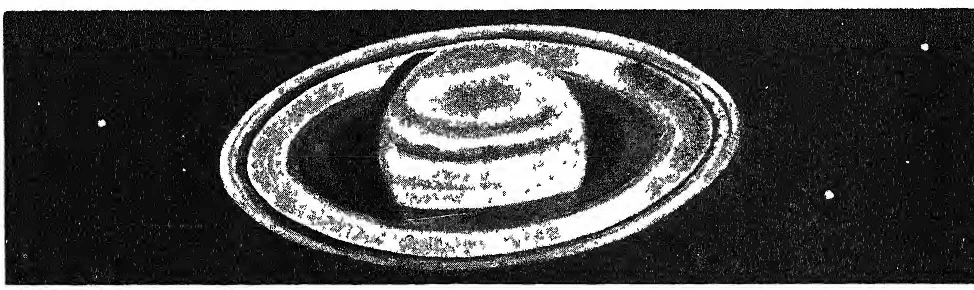
SATURN WITH ITS RINGS SEEN EDGEWAYS

The satellites are also shown in this drawing, and Saturn's size may be gauged from the drawings of the earth and the moon.

The axis is inclined to the plane of the orbit by about twenty-eight degrees, giving the planet very much the same slant as the earth has in its orbit. We can hardly speak of seasons, however, in the case of Saturn, since it has no solid surface like the earth.

The visible surface of Saturn has a reflecting power exceeding even that of Jupiter, and this brilliancy is doubtless due to the fact that the reflecting surface consists of

cloud But Saturn appears to be somewhat brighter even than white clouds, from which some have supposed that the light it sends to us is not wholly due to the reflection of sunlight, but is partially derived from the planet's own glow. This is a matter, however, upon which there is much difference of opinion, but it is probable that the glowing interior is visible to us, for Saturn has belts like those of Jupiter, only not so clearly marked, and the darker zones have the color of a red-hot mass. There is a very brilliant broad white belt round the equator, and the pole has a cap of dull green. Like Jupiter, Saturn is not so brilliant at the edge as towards the center of its disc. The spectroscope reveals a deep atmosphere which gives certain dark lines that have not been observed elsewhere except in the atmosphere of Jupiter.



SATURN WITH ITS RINGS OPENED OUT TO THEIR MAXIMUM
The transparency of the inmost "crape" ring, and the shadow cast by the planet on its rings, should be noticed

Besides its nine satellites, Saturn is surrounded by a vast swarm of small particles, compared by Clerk Maxwell to brickbats, which circulate about the planet in the form of three concentric flat rings. These rings are unique; nothing like them is known elsewhere in the universe, unless they bear some very remote analogy to the swarm of asteroids which circulate about the sun in the space between the orbits of Mars and Jupiter. It was long before the shape of these rings was made out, and longer still before their nature was understood.

They were among the first fruits of the telescope. Galileo, in 1610, examining Saturn with his new instrument, came to the conclusion that the planet had a triple form. "When I observe Saturn," he wrote to a friend, "the central star appears the largest; two others, one situated to the east, the other to the west, and on a line which does not coincide with the direction of the zodiac, seem to touch it. They are like two servants who help old Saturn on his way, and always remain at his side. With a smaller telescope the star appears lengthened, and of the shape of an olive". But continuing to watch this strange portent, month after month, Galileo was amazed to see the two attendants upon Saturn becoming smaller and smaller, until they finally disappeared altogether. He doubted the evidence of his telescope, and even the strength of his own mind "What can I say," he wrote, "of so astonishing a metamorphosis? Are the two small stars consumed like sun-spots? Have they vanished and flown away? Has Saturn devoured his own children? Or have the glasses cheated me, and many others to whom I have shown these appearances, with illusions?" Thoroughly discouraged, Galileo abandoned his observations of Saturn, and died before these strange appearances had been explained.

Others, however, watched the planet whenever it was in view, and gradually established the fact that Saturn's unique appendages underwent regular periodic changes. They appeared first as bright, straight lines stretching outwards one on each side of the elliptical disc; then, for the next seven years, these lines expanded into two luminous crescents attached to the planet like handles to a dish; and then for seven years more, the crescents became flattened down, until, as before, they were mere lines projecting from Saturn, and finally disappeared altogether. For as the planet pursues its vast orbit, slanting al-

ways in the same direction, it twice exhibits its rings, at opposite points in the orbit, edgewise to the earth; and between those two points the surfaces of the rings are exhibited, though always foreshortened, the northern surface being seen for fourteen years and more, and then, for a similar period, the southern surface.

A Dutch clock and instrument maker solves the problem of Saturn's rings

Christian Huygens, a great Dutch scientist and maker of clocks and telescopes, who was the first to bring forward in definite form the wave theory of light, and the first to apply the pendulum to the regulation of clocks, was the first to solve the problem of Saturn's rings. That is to say, he discovered that they were rings, though their constitution was unknown for long afterwards. His discovery was due not only to the greatly improved telescope which his new methods of grinding and polishing lenses had enabled him to make, but also to reasoning power of a very unusual order. Having observed the shadow thrown by the rings upon the planet's globe, and concluding that Saturn, like other planets, was probably in swift rotation upon its own axis, Huygens perceived that a very thin, broad, flat ring, entirely separate from the planet which it encircled, was the only structure that could give rise to all the various puzzling appearances observed.

Yet this hypothesis was so unprecedented, so amazing, that he hesitated to publish it. The theory was sure, in 1655, to meet with incredulity and ridicule. He therefore had recourse to a device common enough at the time, though it seems somewhat absurd now, and published an anagram or cipher which contained the mixed letters of a Latin sentence stating that Saturn "is encircled by a thin, flat ring, not cohering with the planet at any point, and inclined to the ecliptic". Further study convinced him that his theory was invulnerable, and in 1659 he gave his discovery to the world, proving it at the same time by predicting accurately the phases the rings would present in the following years.

The Italian astronomer in Paris who showed that Saturn has two distinct rings

Giovanni Cassini, a learned Italian who was the first director of the Paris Observatory, had made a great reputation by his discoveries with regard to Venus, Mars and Jupiter's satellites before he made the next advance in the elucidation of Saturn's rings. He showed that there was not one ring, but two. A dark circle divides a narrower outer ring from a much broader inner ring. This dark ring was carefully studied by Cassini, Herschel and others, until it was clearly shown to be not a dark circular marking on a single ring, but a definite space between two concentric rings. This dividing space is known as "Cassini's division". The inner and the outer rings are not of equal luminosity. Cassini compared them very justly to polished and dull silver respectively.

Further examination of these rings has added to the complexity of the system. Johann Encke, a German astronomer and director of the Berlin Observatory, whose name is remembered chiefly in connection with a comet he discovered, pointed out in 1837 that the outer ring of Saturn is itself divided by another dark line, as broad but not so clearly defined as Cassini's. Encke's line can only be made out with a powerful telescope, and under favorable conditions in the position of the planet and in the terrestrial atmosphere. It is evidently not a clear division right through the outer ring, but rather a line or area in which the ring is much thinner than elsewhere.

The occasional divisions in the planet's rings that are not permanent

A year later De Vico saw two more dark lines on the inner ring, but these markings were not permanent divisions. Of these and similar discoveries Sir Robert Ball remarks that "occasionally other divisions of the ring, both inner and outer, have been recorded. It may at all events be stated that no such divisions can be regarded as permanent features. Yet their existence has been so frequently enunciated by skilful observers that it is impossible to doubt that they have been sometimes seen."

Cassini's and Encke's discoveries were followed, in 1850, by another of a surprising nature. In that year, W. C. Bond, of Harvard, and William Dawes, an English astronomer, discovered at the same time, but independently, that Saturn has three rings, and not two as had hitherto been supposed. The third ring was observed to lie immediately within the inner of the two which were already known, and to occupy about half the space between that ring and Saturn's globe.

This "gauze" or "crape" ring, as it is often called, because of its filmy and half-transparent texture, is very dark as compared with the two rings which surround it, and had escaped observation on that account. It was not, as some were inclined to suppose at the time, a new structure, for many drawings made by earlier astronomers showed clear traces of it.

Is the gauze, or inside ring of Saturn becoming more visible?

It differs remarkably from the two outer rings, which have a solid appearance, although we know that they cannot really be solid, for the body of the planet can be seen clearly through this dusky ring. Sir Robert Ball was of opinion that the increasing facility with which the crape ring is seen is only partially due to the fact that astronomers have learned what to look for, and that there is a real change going on, by which it is becoming more substantial.

According to Barnard's measurements the equatorial radius is 38,235 miles. The diameter of the whole ring system, to the outer edge of the outer ring, is about 172,600 miles. This outer ring is about 11,100 miles in breadth; then follows Cassini's division, the dark line or area, which is about 2200 miles wide; then the middle ring, with a width of about 18,000 miles; then, without any clear separation, the crape ring, about 11,000 miles in breadth; and lastly, a space of about 7000 miles between the inner edge of the crape ring and the planet's globe. The breadth of the system of rings, from the outer edge of the outer ring to the inner edge of the crape ring, is close to 42,000 miles.

The rings all lie in one plane—that is, the plane of Saturn's equator. Their thickness probably does not exceed, according to Barnard's estimate, 30 miles. Professor Russell puts it at about 21 kilometers or 13 miles. So thin are they that when they are presented edgewise to the earth they disappear altogether.

At our passage through their plane which occurred in 1907 and in 1908 and again in 1920 and 1921, even Barnard, who was one of the keenest observers America has ever had, was unable to see even a trace of the rings with the great 40-inch telescope of the Yerkes Observatory. At both of these periods there appeared luminous knots or condensations on the rings; these condensations were of considerable thickness and were thought by some astronomers to be due to accumulations of matter in certain sections of the rings, but, according to Barnard, the observations all showed "that these appearances were not due to actual condensations or thick places of the rings, for they were entirely invisible near and at the time when the ring was edge on to us. This proved that they were really the obscure surface of the ring illuminated by sunlight sifting through or among the individual particles composing the rings, and thus making them more or less feebly visible."

The unsolved mystery of the constitution of the rings

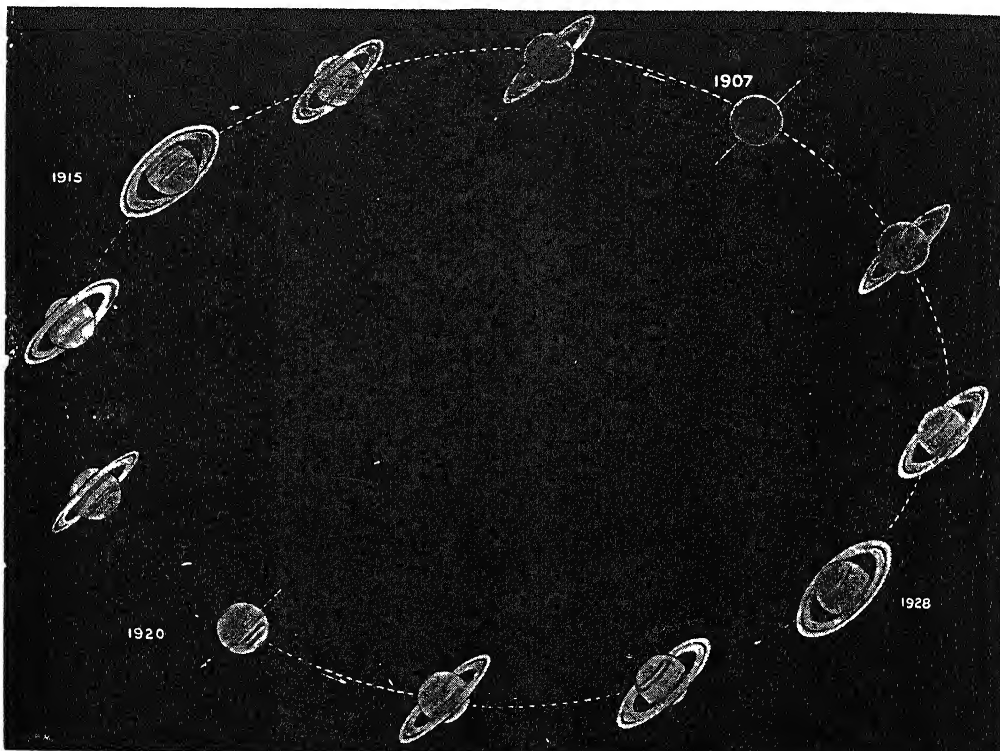
No wonder the question of the constitution of Saturn's rings became one of the greatest puzzles in astronomy. Their vast expanse, their excessive thinness, their lightness, which is such that they have been compared to immaterial light, their evident opacity, so that they throw a shadow on the planet's globe, and, above all, the absence of any other structure in the heavens wherewith they can be compared, combine to deepen their mystery.

Astronomers soon realized that solid rings were out of the question. In the first place, solid rings would be in a position of unstable equilibrium; for, as soon as the rings should shift in the least degree nearer to the planet at one point than at another, there would be a greater pull of

gravity on that point, and the rings would fall into the surface of the globe. And in the second place, even though equilibrium should be maintained, each ring would be like a stupendous arch built across the heavens; and no material could stand the crushing stress of the weight of the arch.

Nor would the centrifugal force developed by the swift rotation of the rings, however great it might be, really relieve solid structures of these dimensions from strains and stresses which would immediately shatter them; for centrifugal force would be greater at the outer edges of the rings than at their inner edges, while, conversely, gravitation would pull more heavily on the inner than on the outer edges. Nothing that we know could save solid rings from instant disruption.

As an alternative to solid rings, it was early suggested that they might perhaps be fluid, but mathematical investigation showed that violent wave-motions would inevitably be set up in the fluid rings, and would quickly destroy them. But the exclusion of these impossible theories leaves us with only one possibility, which has long held the universal assent of the scientific world. The rings are made up of innumerable entirely separate particles. As to the size and nature of these particles we know nothing. But whether they average the size of the motes of dust which dance in a sunbeam, or are as big as houses or as mountains, each of them is really on its own account an independent satellite of Saturn. This only possible explanation of the rings of Saturn was suggested by Cassini, as early as 1715, but it received little attention until the discovery of the half-transparent crape ring, which was evidently no continuous body, whether solid or fluid. Finally in 1895 Keeler proved by spectroscopic observations that the period of rotation of different parts of the rings is precisely that required by a set of independently moving satellites, the inner



THE DIFFERENT PHASES OF SATURN'S RINGS AS SEEN FROM THE EARTH IN THE COURSE OF ITS TWENTY-NINE AND A HALF YEARS' JOURNEY ROUND THE SUN

portion having a period of 5 hours, and the outermost, a period of 137 hours. The remarkable divisions between the rings still, however, remained a mystery. Why should the outer ring show a partial cleavage in Encke's division?

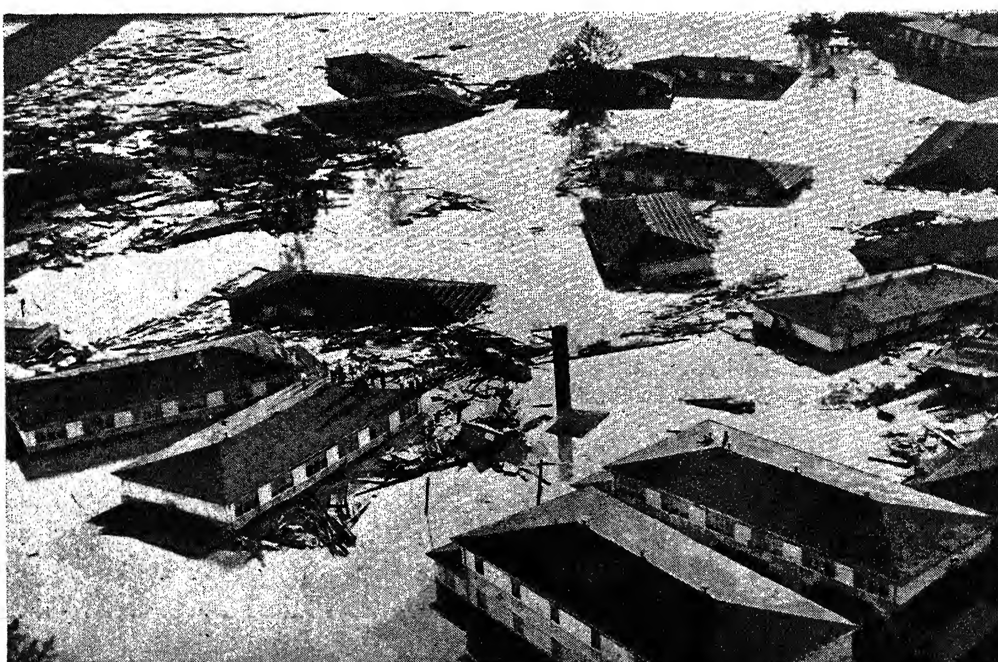
When meteors are all about, and are moving freely, and are doubtless continually jostling and colliding with one another what unseen force sweeps them out of the 1600-mile-wide area of Cassini's division? Here the only plausible answer was first suggested by the American astronomer Kirkwood. The reader may perhaps remember that similar clean-swept spaces are found amid the intricate tangle of the orbits of the asteroids, and that the unseen influence there at work is the gravitative power of the giant Jupiter. Any asteroid pursuing an orbit within one of these spaces would be circling round the sun in a period commensurable with the period of Jupiter in its orbit. That is to say, it would complete its circuit exactly twice in the time which Jupiter takes to revolve once round the sun, or would perform five revolutions for two of Jupiter's, or by some other simple arithmetical relation of this kind would frequently be subjected, at the same point in its orbit, to the same pull from Jupiter. The result would be that any such asteroid would be pulled out of the orbit in which it synchronized with Jupiter into another orbit in which it would no longer be subjected to a constantly recurring pull in the same direction. A precisely similar influence has been at work upon the myriad meteors of Saturn's rings, sweeping Cassini's division wholly clear of meteors, and Encke's division perhaps only partially clear of them. In this case, however, the disturbing agency has not been another planet, but has been the major satellites of Saturn itself, or, rather, the three inner satellites, which, being the nearest to the rings of meteors, have had the greatest influence upon them. Mathematical calculations show that the satellites known as Mimas, Enceladus and Tethys revolve round Saturn in periods which are precisely commensurate with the periods of any meteors which should occupy the spaces or divisions between the rings. The three rings are due to these three satellites.

So far as is known at present, Saturn has nine satellites. The first was discovered in 1655 by Huygens, who solved the problem of the rings; Cassini found four more in the years 1671, 1672 and 1684; Herschel two more in 1789; an eighth satellite was discovered in 1848 simultaneously by W. C. Bond, of Harvard, and Lassell, an English observer; the ninth was found in 1898 by Prof. Pickering using photographic methods. He also claimed to have discovered a tenth in 1904. Both were extremely faint but the tenth has not been observed since and is not regarded as a satellite.

RAIN AS FRIEND AND FOE TO MANKIND

British Information Services

Rain is a welcome ally to the cultivators of these flourishing rice fields near Srinagar, Kashmir.



Wide World

Excessive rainfall may lead to grim disaster, as this scene of havoc in Vanport, Oregon, attests.

RAIN AS FRIEND AND FOE

Why It Rains — How Much It Rains — and the Queer Things that Rain Can Do

THE RED RAIN OF SUPERSTITION

RAIN consists of drops of condensed water-vapor of varying size which fall from a height through the air at a comparatively rapid rate. The fall is hastened by the running together of the fine drops in a raincloud. The combined drops have a smaller surface in proportion to their weight than the individual drops had before their combination; the air accordingly offers them less resistance, and they fall, therefore, more readily and rapidly. Though as a rule rain falls from a cloud, it occasionally, as is well known, happens that rain falls from a perfectly cloudless sky.

This takes place when the air contains too few dust-particles to provide for the condensation of the numerous little droplets that go to the making of a cloud. The moisture, therefore, instead of beginning in little droplets as a cloud, condenses at once as big drops on the scanty dust-particles, and falls at once as rain.

Rain does not necessarily reach the earth. A cloud may rain, and yet the drops of rain may evaporate before they reach the earth, and no doubt this happens more often than is commonly supposed. The condensation that results in rain is quite simple in its general principles. The warmer the air, the more water-vapor it can hold. When, accordingly, warm air containing a certain quantity of water-vapor is cooled, it becomes, at a certain point — called the "dew-point" — incapable of holding all the water-vapor it could hold when warmer, and the vapor accordingly condenses on any solid, cool particles it can find. A cooling by any means of warm, vapor-laden air is the ordinary origin of rain. This cooling may be effected in various ways: by a cool breeze, or by a cold hill, or by expansion — as when a breeze blows uphill. In mountainous districts both the last two conditions are found, and hence in such there is usually a large rainfall.

The cloud that so often attaches itself to the summit of a high peak is not a cloud that has caught there, but that has been formed there; and often, as the wind blows over a snowy peak, a cloud streaming from the peak like a pennant demonstrates the condensation of the water-vapor it contains. The condensation of the escaping steam of a locomotive, and of the breath on a cold day, are illustrations of the same process on a small scale. All that is required is water-vapor, sufficient cold to condense it, and nuclei, such as dust-particles, to serve as centers of condensation.

From what we have already said, it is evident that the distribution of rain must depend largely on the physical features of the land. In a general way, the following rules may be laid down.

Towards the equator the rainfall increases, and towards the poles it diminishes. The reason of this is that the heat of the tropical zones evaporates the greatest quantity of water and the vapor thus formed is readily precipitated.

Other things being equal, there is more rain near the sea than inland. First because a wind from the sea is likely to contain a quantity of water-vapor; and second, because the land and the sea are often of different temperatures, and thus a warm, moist wind off one may be condensed by the other.

Other things being equal, the rainfall increases with the height above sea level, provided always a height above ordinary cloud-level is not attained. This is due to the action of mountains in condensing water-vapor, as we have already explained.

The average rainfall of the plains of Europe is 22.6 inches per year, whereas in mountainous districts it is over 50 inches. In the valley of the Rhine, the average rainfall is 22 or 23 inches; in the Vosges mountains it reaches 47 inches in certain districts. At Arles, it is 17 7 inches, while at Joyeuse, in the mountains sixty miles away, it averages 51. At Geneva, it is 32 inches; at the St. Bernard Hospice, 79.

In the United States the annual rainfall along the Atlantic Coast varies from 30 to 80 inches, the mean annual precipitation in New York State being 39.3 inches; along the western slope of the Continental Divide the precipitation is abundant, reaching in some localities 135 inches a year, but in the interior it is generally smaller, being in a number of states less than 15 inches a year.

The rainiest district in the world is probably the lower slopes of the Himalayas. Here all the physical conditions conduce to a heavy rainfall We have the steaming water in the great Indian Ocean, and the barrier of the Himalayas, which intercepts the wet monsoons and condenses the moisture they contain Even on the delta of the Indus the rainfall is considerable, but it is when the moist currents reach the hills that the really heavy rains begin. At Ulu Selangor, in the Malay Peninsula, there is an average annual rainfall of 323 inches. At Mahabuleshvar, on the western slope of the Ghauts, it is 275 inches; while at Cherrapunji, on the Khasi Hills, 200 miles north of the Bay of Bengal, it reaches almost 500 inches. Recently during the first ten months of the year, no less than 560 inches fell at Cherrapunji, nor is this a record, for in 1861, 805 inches were registered, and of that total 366 inches fell in July. Sixty-seven feet of rain in a single year! As much in that month of July as falls at Leh, on the other side of the Himalayas, in 100 years!

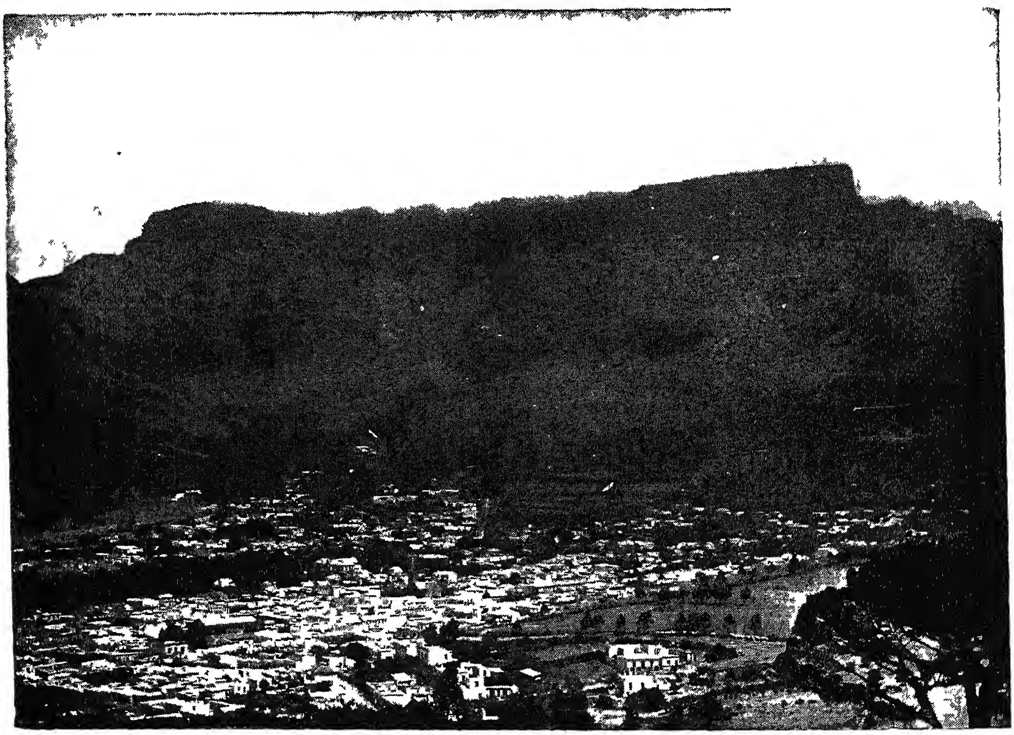
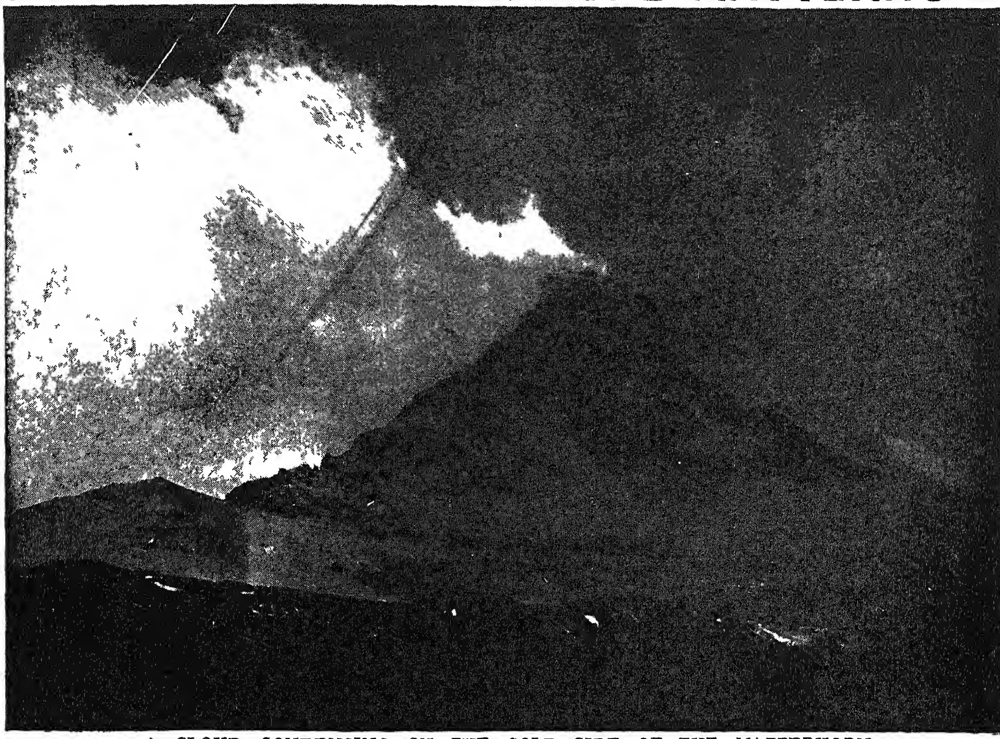


TABLE MOUNTAIN, NEAR CAPE TOWN, COVERED BY ITS TABLECLOTH OF CLOUD

THE CLOUD-BANNER OF THE MATTERHORN



A CLOUD CONDENSING ON THE COLD SIDE OF THE MATTERHORN

A CLOSE VIEW OF THE MIST-LIKE CLOUD ON THE SLOPES OF THE MATTERHORN

In this place of truly amazing wetness 40 inches of rain have fallen in 24 hours; this equals 224 gallons or nearly one ton of water on each square yard of surface There are places in Europe where there are occasionally terrific rains At Joyeuse, in France, 31 17 inches fell in 22 hours, at Geneva, 30 inches in 24 hours; and at Gibraltar, 33 inches in 24 hours. But the heaviest downpour on record occurred in November, 1911, at Porto Bello, Panama, when 2.48 inches fell in 5 minutes. Fortunately for Panama such a rainfall is not typical of its climate.

The movement backward and forward of this great girdle of clouds makes a regular alternation of wet and dry seasons in the tropics; and the rainy season is in summer, so that there are clouds and rain just when they are most wanted In the immediate neighborhood of the equator there are two dry and two wet seasons How much rain falls on the tropical seas cannot be calculated, but the amount must be very large Occasionally the rainfall is so heavy that sailors are able to collect a supply of fresh water from the surface of the ocean

A RAIN-WROUGHT LANDSLIDE OF BLUE CLAY ON THE HAMPSHIRE COAST, ENGLAND

The heavy rainfalls in the tropics are not due to condensation of moisture by mountain ranges so much as to the condensing effect of cold winds pouring in from cooler regions The line of meeting moves north and south with the movement of the sun When the sun is north of the equator the zone of clouds is also north of the equator, and when the sun is south of the equator the zone of clouds is found in the southern hemisphere Reclus says: "It is undoubtedly visible from the nearest heavenly bodies, and must resemble those whitish bands which our telescopes discover on the planet Jupiter"

In the temperate zones there are no clearly defined dry and wet seasons, and the rainfall is much more irregular, depending on numerous variable factors. On the Southern Russian steppes and in the Hungarian highlands the heaviest rainfall is in summer, while in Spain and Portugal the heaviest rainfall is in autumn and winter

In certain regions of the globe there is almost no rain. Very rarely does it rain in the districts south and east of the Caspian Sea, on the African Karoo, in southern Australia, in the Arctic regions, in the regions south of latitude 60°, and in

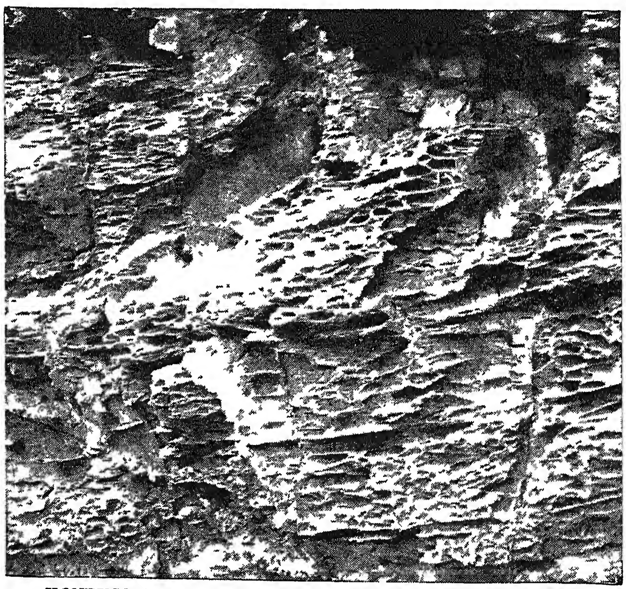
A RAIN FOREST OF THE SOUTH PACIFIC

Standard Oil Co (N J)

Matted jungle growth at Klamono, New Guinea. The forests of New Guinea abound in enormous trees

the canyon country of Arizona And a strip of the western slopes of the Andes, extending southwards through Peru and part of Chile from latitude 5° S. to about latitude 35° S. is altogether rainless, all the rain being retained by the mountains that rise to the east In Peru "the appearance of a cloud is a real event, and the whole population assembles to contemplate this unaccustomed spectacle" Rainless, too, is a belt of land, about 10° in breadth, which, extending across Africa, including the Sahara and Libyan deserts, crosses the north of Arabia into Persia to terminate near the western border of Afghanistan. And still a third rainless region includes eastern Turkestan, with the Desert of Gobi.

Where there is no rain, the contours of mountain and plain have a characteristic monotonous appearance. There are no glens, valleys and streams — only flat plains and level plateaus. Where there is no rain there is also no vegetation except lichen. Dry, dusty desolation prevails throughout the length and breadth of the rainless land.

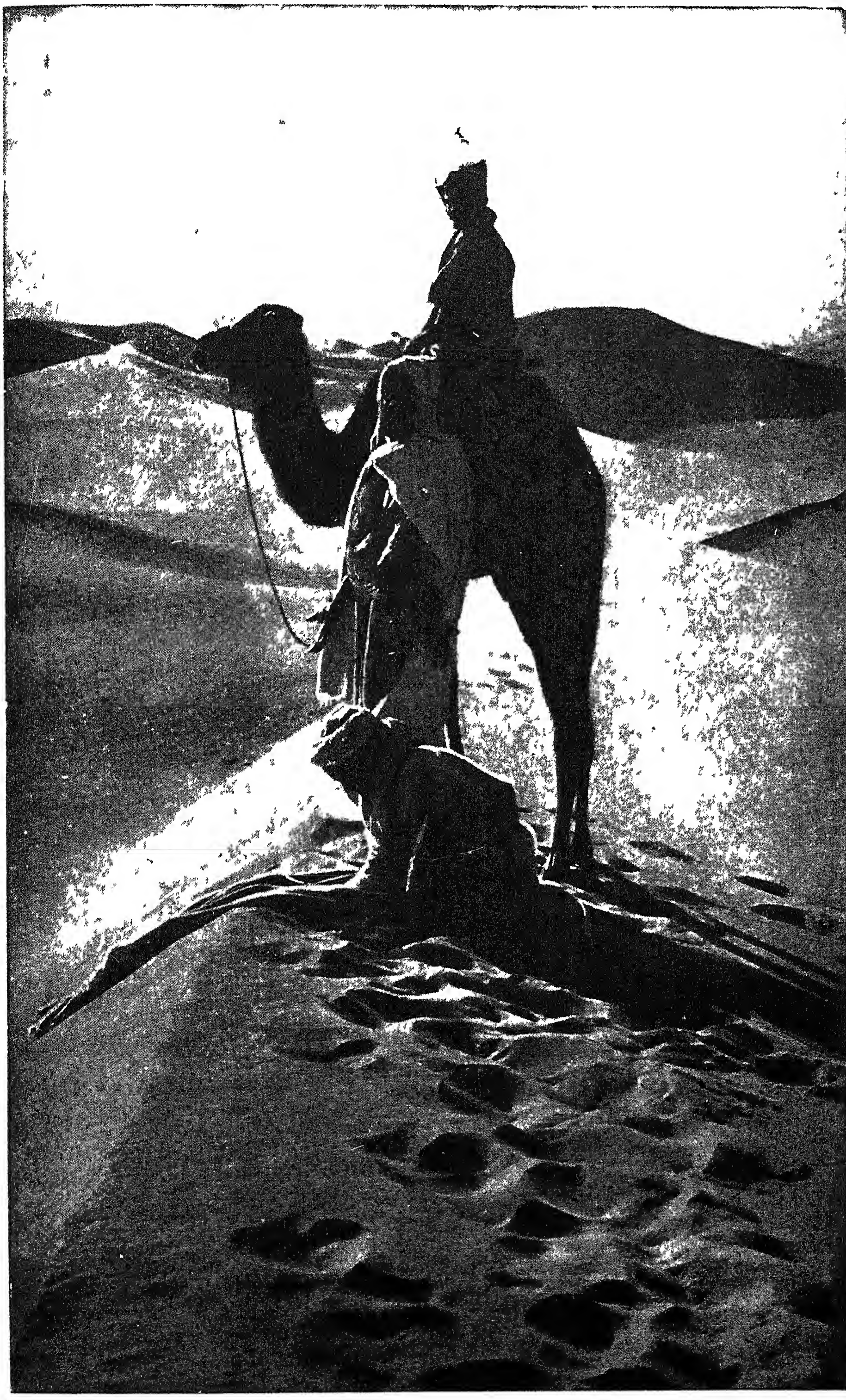


HONEYCOMB WEATHERING AT PORTSCATHO, CORNWALL

Where the rainfall is small it is of the utmost importance On the African Karoo when the rains fail all the vegetation of the Karoo perishes, and sheep and other animals die of lack of food And when the rains do come the sudden response of vegetation to the moisture is like a miracle. When there is a dry season and a wet season, the wet season is like a resurrection. Reclus describes how in the dry season the soil of the llanos of Colombia dries up: "The watercourses become exhausted; the lakes change into pools and then into sloughs, in the mud of which crocodiles and serpents delight to wallow; the clayey ground shrinks and cracks, the plants wither and are torn to shreds by the wind, the cattle, driven by hunger and thirst, take refuge in the neighborhood of the great river, and multitudes of their skeletons lie bleaching on the plains . . . All at once the storms of the rainy season inundate the soil, multitudes of plants shoot out from the dust, and the yellow expanse is transformed into a flowery meadow" It is little wonder that in some savage tribes the rain-doctor is a personage of some importance.

It has often been maintained that trees bring rain and that the felling of forests decreases the rainfall. There is no doubt at all that the deforestation diminishes the permeability of soil, and diminishes, too, its capacity for catching and holding water. Trees both collect water round their roots and hinder its evaporation by means of their foliage. Where trees overshadow a road is usually the part of the road that takes longest to dry.

Where trees overshadow a spring they conserve its water for the dry seasons There is no doubt that in these ways trees collect and conserve rain, but whether they actually attract rain is rather a moot question. On the whole, it seems probable that trees do in some way attract the rain. "It must not be forgotten," writes Dr. Robert Brown, "that the slightest difference in the temperature of the soil, especially of the hills, over which a vapor-laden cloud is sailing, may determine whether its moisture will be condensed



AN ARAB OUTPOST KEEPING WATCH AMONG THE SAND DUNES OF TRIPOLI

and precipitated, or whether the misty vapor will float away without the thirsty earth obtaining the benefit of its contents, here more grudgingly bestowed than in the cooler regions near the poles." Certainly trees do not retain heat, and they are usually cooler than the soil.

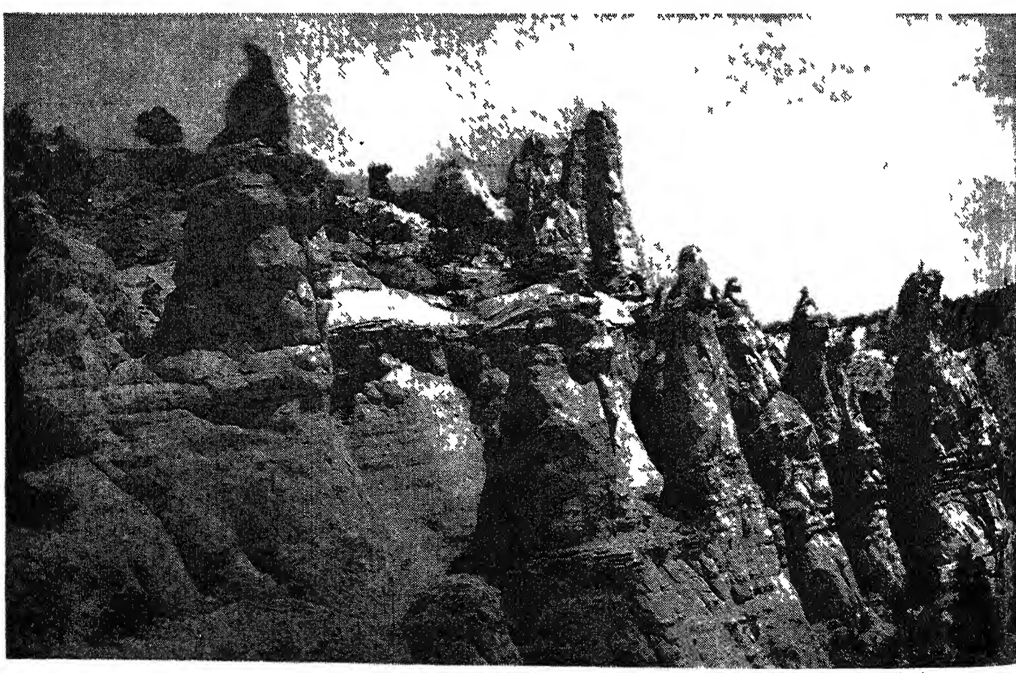
Whether by favoring condensation, whether through the high electrical tension of the tops and tips, there seems a fair amount of evidence that forests directly attract rain, and that deforestation leads to drought. The cutting down of trees in St. Helena was followed by a decrease in the rainfall; a replanting of trees was followed by increased rainfall.

Drought brings with it the ever present danger of forest and prairie fires. After weeks of dry weather, grass and shrub and tree are like tinder, ready to catch fire, and a very small spark may kindle a destructive blaze. Sometimes even the friction of two branches against each other may suffice to kindle a flame. Forest and prairie fires sometimes spread for many miles. In 1923 whole towns were wiped out in the southern part ot the state of California.

Rain plays a very important part in molding the face of the earth. Its action in this particular process is partly chemical and partly mechanical.

In considering the chemical action of rain, we must bear in mind that it is not pure water. In the atmosphere it absorbs atmospheric gases — oxygen, nitrogen and carbon dioxide. These are found to be absorbed in the following average proportions: nitrogen 64.47; oxygen 33.76; carbon dioxide 1.77. The absorbed gases are not found in the same proportion as in the atmosphere; the carbon dioxide occurs in proportions thirty to forty times greater than in the atmosphere. Besides these natural atmospheric gases, rain also absorbs a certain amount of nitric acid, sulfuric acid and salts. It also carries down with it germs and dust. As soon as it touches the earth it adds to its chemical contents.

Rain, accordingly, contains various more or less active chemical substances and has a varied chemical action on the rocks and soil on which it falls. Owing to its oxygen, it oxidizes or rusts various minerals, such as iron, which it passes over.



Soil Conservation Service

Odd erosional formation in soft sandstone in the land of the Navajos near Gallup, New Mexico.

Owing to the organic matter it contains, it deoxidizes other minerals such as gypsum. And owing to the carbonic acid it contains, it dissolves limestone and marble, carbonate of magnesia and other minerals. The so-called "pipes" and "swallow holes" found in limestone rock are funnel-shaped cavities corroded in the limestone by rain. If there is no soil on the surface to fill up these holes, they deepen and may eventually become caverns.

The Carso district in Yugoslavia is honeycombed with these holes, which are locally known as *dolniens* or *dolinas.* Some of them are deep (the deepest is 525 feet); some shallow. At the bottom is found a red earth — the insoluble iron-oxide residue of the limestone. In northern Bohemia and Saxony hollows 3 to 30 feet deep, known as *karren* or *sehratten,* are found, and these doubtless are also formed by rain eroding the limestone rock.

U. S. Geological Survey

This strange formation is a most striking example of the way in which rain sometimes carves rock.

Even granite is rotted by water, so that it becomes loose and can be dug into with a spade. It is mixed with clay and sand. In the District of Columbia granite has been found decomposed to a depth of as much as 80 to 100 feet. Near St. Austell, in the English county of Cornwall, huge pits, as big as skyscrapers, have been dug into the granite by miners in search of tin and china clay.

In some cases when rain is absorbed by rock, the latter forms a chemical compound with the water and undergoes the change known as hydration. Anhydrite, for instance, is converted into gypsum, and it increases in bulk at the same time about 33 per cent.

The mechanical action of rain is quite obvious. Every heavy shower of rain scours and scars the roads and paths with its runnels; and when the rain comes down in sheets it carries away the soil as effectively as a river. Where there are trees and vegetation to shield the soil and to hold it together, the rain may fail to remove much of it, but where the soil is unprotected it may be quickly carried away. The destruction of forests, accordingly, is bound to increase greatly the destructive effect of rain, and many parts of Syria, Greece, Asia Minor, Africa and Spain have first been denuded of trees by men, and then of soil by the rain. "If," wrote Reclus, "some modern Attila, traversing the Alps, made it his business to desolate these valleys forever, the first thing he should do would be to encourage the inhabitants in their senseless work of destruction."

In some cases torrential rain produces floods of mud; a catastrophe of this kind occurred near the volcano of Vesuvius, in Italy, in September 1911.

"The torrential rains which fell caused a huge volume of mud and lava to flow down the sides of the mountain, and this, dividing into several branches, swept over the entire countryside, destroying everything in its path The town of Resina was completely engulfed in it, and the mud gradually reached the height of the first-floor windows of the houses. To describe the horror of the scenes that ensued one would be obliged to have recourse to the most awesome incidents in Dante's *Inferno* The floating corpses of people who had been overtaken by the terrible

flood presented a dreadful spectacle on the surface of the lava. Farming utensils and furniture, together with cows, horses, and various other domestic animals, were also caught up and borne along by the stream. The district of Miglio de Oro, one of the most enchanting parts of the commune of Resina, has been flooded with mud and totally ruined. The onrush of the lava was such that many houses were swept away bodily. . . .

"The scene at Resina is described as dreadful. The impetuous torrent rushed

ESCAPING FROM THE VESUVIAN MUD-FLOOD

down the mountain-side, and burst with great force against the walls of the houses. The doors crashed in, and the thick stream of lava flooded the lower floors, ruining the interiors of the dwellings. In many cases the mud inside the houses flooded the stairs and the upper floors, breaking practically all the windows in the town. Many persons, particularly women and children, were so terrified by the unusual sight that they had not even sufficient energy left to save themselves, and they were consequently drowned by the awful torrent that still came pouring down the mountain-side. Some time afterwards many bodies were recovered, the faces in every case bearing an expression of the utmost horror. Vivid flashes of lightning and peals of thunder added to the terror of the inhabitants."

A similar mud-stream occurred in the Philippine Islands in 1876. Torrents of rain descended on the volcano Mayon, and a deluge of mud, cinders and ashes broke down bridges, blocked roads, destroyed villages and wrecked over six thousand houses.

In other cases rain destroys, not by causing deluges of mud such as we have described, but by producing landslides, in which rain plays a triple part — it disintegrates the soil, it loosens its attachment to underlying rock and it adds immensely to its weight. Frost, too, takes part in the process, by causing a general expansion of the water in the crevices and pores of rocks and soil, and many severe landslides take place during or after frosty weather. The numerous landslides on the coast attributed to the sea are often mainly due to the rain — the sea merely giving the finishing touch to the loosened mass. Much, too, that is attributed to rivers is really due to rain. We are accustomed to think of rivers carving out the broad valleys, but probably half the work is done by rain, tumbling the banks into the river. All that rivers can do without rain is seen in the rainless canyon country of Arizona, where the rivers make not valleys and glens but cut steep gorges with perpendicular banks. If the canyon country should come to have a rainfall like Cherrapunji its contours would very soon be completely altered.

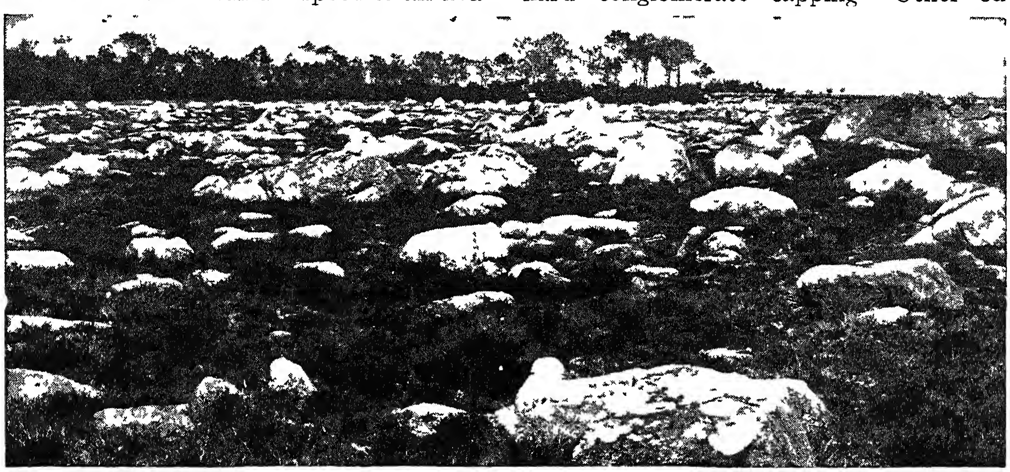
Most of the great landslides occur among mountains. In 1806, after heavy rains, a huge mass of pudding-stone broke loose from the Rossberg, a mountain in Switzerland, near the Rigi, and in a few minutes the village of Goldau and three adjacent hamlets, together with 433 natives and 24 visitors, were buried 100 to 200 feet deep. So violent and rapid was the movement that the friction of the rocks striking and rubbing against each other gave rise to flames which "broke in fiery jets from the half-opened mountain". The lake of Lowerz was partly filled up, and the pre-

cipitation into it of such a mass of debris gave rise to waves that swept away all the houses on its banks. Even birds flying in the air were killed. It is estimated that the falling mass contained more than 54 million cubic yards, and measured $2\frac{1}{2}$ miles long by 350 yards wide and 35 yards thick. A landslide in 1881 at the Tschingel Alp had almost as disastrous consequences, destroying the village of Elm and most of its inhabitants. This fallen mass contained enough stone to build a city. In 1618 a slide occurred at Monte Conto which buried the town of Plurs, with 2430 inhabitants; and though attempts were made to dig it out no trace of it could be found In some cases landslides rush down with the speed of an avalanche, and propel compressed air before them with such force that villages are blown away.

But rain does not always act in such a dramatic and tragic fashion; sometimes its work is merely fantastic, like the tall pinnacles of stony clay known as earth-pillars. They occur in the Tyrol, in the Himalayas, in the Sierra Nevada, at Fochabers, in Scotland, and in other parts of the world. Very characteristic and remarkable are the earth-pillars which occur in a glen on the Rittnerhorn, in the Italian Tyrol. The glen has been cut out of clay by a mountain stream, and on either side it is fringed with these earth-pillars, from 8 to 30 feet high, and "crowded like tombs in an overfull churchyard". Almost every pillar is capped with a boulder. In the Sierra Nevada some pillars reach a height of 700 feet. They are simply hardened columns of clay, which, protected by their capping of stone, have resisted the eroding power of the rain, while all the clay round about has been washed away. If the capping stone falls off, the rain soon melts the pillar away, or cuts it down until another stone protects it again from further erosion.

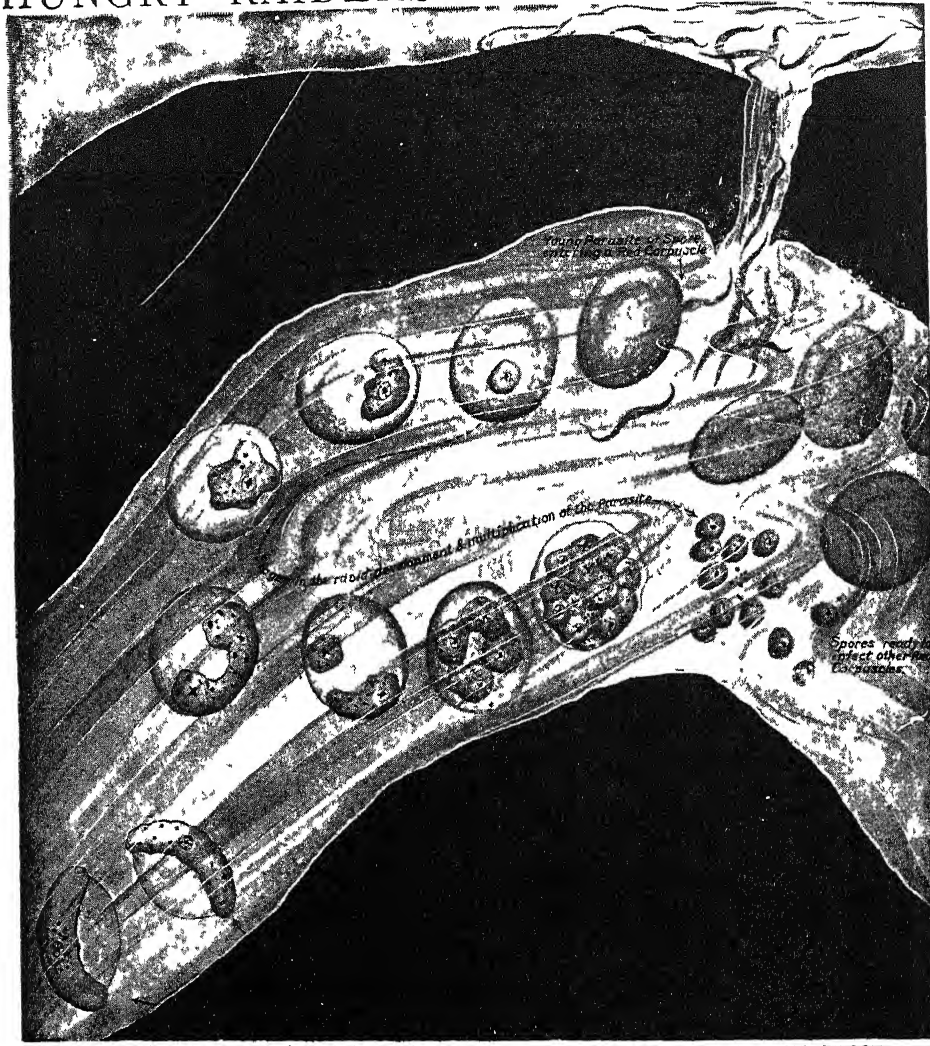
Mount Roraima, in British Guiana, a mountain rising 8580 feet and consisting of soft sandstone capped with conglomerate, is thought by some to be really a gigantic earth-pillar, its soft sandstone having been protected from the rain by its hard conglomerate capping Other curious achievements of the rain are seen in the "Stone Rivers" of the Falkland Islands. Most of the valleys in the East Island are filled with large, angular blocks of quartzite covered with a thin, extremely hard white lichen, which looks like a coating of ice. "Far down below, under the stones, one can hear the stream of water gurgling." Exactly how these Stone Rivers are made is not known, but they are certainly the product of the disintegrating and denuding action of rain.

Other bizarre and rococo results of rain are seen in the remarkable piles of stones found here and there all over the world, and usually known locally by such names as "Devil's Castle", "Lover's Seat", "Grandfather's Chair", etc.

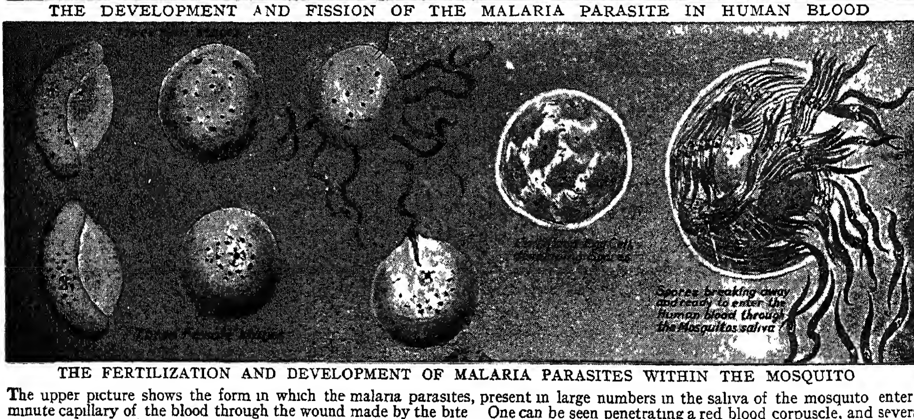


RESIDUAL BLOCKS OF WEATHERED GABBRO ON THE CROUSA DOWNS, ST. KEVERN, ENGLAND

HUNGRY RAIDERS OF HUMAN BLOOD



THE DEVELOPMENT AND FISSION OF THE MALARIA PARASITE IN HUMAN BLOOD



THE FERTILIZATION AND DEVELOPMENT OF MALARIA PARASITES WITHIN THE MOSQUITO

The upper picture shows the form in which the malaria parasites, present in large numbers in the saliva of the mosquito enter a minute capillary of the blood through the wound made by the bite One can be seen penetrating a red blood corpuscle, and several successive stages of the parasite's development and multiplication by fission are shown the free spores thus formed being capable of infecting fresh corpuscles The sexual types of the organism, shown in the bottom left-hand corner, will pass into the mosquito through the human blood, upon which the mosquito feeds These sexual varieties go through the series shown in the lower picture in the body of the mosquito, finally developing into the spore form which infects the human species through the wound, as shown above.

THE OMNIPRESENT PARASITE

The New World of Internal Life, Hitherto Invisible, Revealed by the Microscope

THE PLACE OF PARASITES IN DISEASE

STRICTLY speaking, it is not so easy to define parasitism, for any definition will be almost certain unintentionally to include, for instance, man as a parasite upon the cow, whose milk we consume All forms of life are so interdependent that, from one point of view, anything specially to be called parasitism can scarcely be distinguished at all We must also exclude symbiosis, as illustrated in the lichen, where two forms of life are bound up in a mutually advantageous partnership We must exclude saprophytism, the case of those many vegetable organisms which live upon *dead* organic matter or upon organic products. In the strict definition, man would be saprophytic rather than parasitic upon the cow, for milk is not itself alive. We must confine parasitism to the cases where one living creature lives upon and derives its food from the tissues of another creature, which is called its host.

It is usual to include in the concept of parasitism the idea of injury to the host, but that is not absolutely necessary. No doubt the incidental injury to the host is very important, and, indeed, matters everything to ourselves, who are liable to be the hosts of so many unwelcome and even deadly guests There are plenty of cases of parasitism where it is impossible to say that the host suffers any injury, but the parasite is definitely a parasite, none the less Bacteriologists have identified some thirty different forms of bacteria among what they quaintly call the "flora" of the mouth, but most of these are entirely innocent, no doubt. Similarly, the "flora" of the bowel includes many forms which are harmless. But if they depend upon the host for their sustenance without making any returns beneficial to the host, they must be considered parasites even though they inflict no apparent injury. A parasite exacts something for nothing.

It may fairly be said that parasitism is a universal fact of the living world This was long ago stated in the familiar lines—

> Great fleas have little fleas upon their backs to bite 'em,
> And little fleas have lesser fleas, and so *ad infinitum.*

We shall soon see that this is far truer than anyone could guess until the perfection of modern microscopy But these lines may serve to remind us that parasitism, in its more familiar form, means the presence of smaller organisms upon the exterior of a larger one, as in the case of the flea We now know, however, that parasites may just as well thrive inside the body of their host. The convenient distinction may thus be made between ecto-parasites and endo-parasites, which live respectively without and within the body of their host.

Everyone is familiar nowadays with the bacteria, many of which are parasitic Their dimensions may be very small, as in the case of many round forms, called cocci, which may have a diameter of as little as one *micron*, which is the twenty-five-thousandth part of an inch A millimeter is about one-twenty-fifth of an inch; but so minute are the dimensions of these creatures that we require to use a new unit, called the micron, which is the thousandth part of a millimeter.

It may very naturally be supposed that such dimensions would be the very limit of living forms, and until lately it was so supposed. But recently the lines of the versifier have been justified. We now have good reason to believe that still more minute organisms, the dimensions of which can be expressed only in millionths of an inch, are to be found parasitic upon the bacteria.

When we study the limits of microscopic vision, which depend upon the wave-length of light, so that, even by oblique illumination with light having a wave-length of, for instance, one-40,000th of an inch, we can see objects of at least only half that dimension, it will be realized that these minute organisms are ultra-microscopic. Their existence may be demonstrable by their effects, and their properties may be definable, but, except in indirect and partial fashion, the eye of man cannot hope ever to see them.

Parasites so small that the microscope cannot detect them

This discovery of ultra-microscopic forms of life is so important that we must briefly refer to it further before we proceed with the subject of which they are only the most extreme illustration. In due course we shall learn that there are several diseases in which no one can doubt that a parasite is involved, but no such parasite can be found. Infectious material may be searched by every modern refinement of technique and staining, but nothing can be seen in it. Students have long suspected the reason to be that the parasite in these cases was ultra-microscopic, a suspicion which we must now accept as verified. It raises many new problems, for evidently we are deprived of our right hand when the microscope itself fails us.

It is quite likely that the unknown parasite which produces foot-and-mouth disease in cattle belongs to this category of the ultra-microscopic. We may just remind ourselves, however, that it is only in recent years that the bacteriologists have been at all justified in the assumption that what they cannot see is invisible, and in some instances, no doubt, they will be able to disprove their own suspicion.

So much depends on technique. If we follow the proper procedure we can always readily find the tubercle bacillus, when it is present, but that procedure involves treating the bacillus with something which enables it to hold a certain dye or stain, and then applying the stain in question. Until we go through this procedure in just the right way, we may look for years and find nothing, as Koch did in this very case before he succeeded.

The progress of the discovery of organisms too small for sight

Another instance is furnished by the parasite of syphilis, which was discovered by Schaudin in 1905 and which is really quite long, but is so exceedingly slender and transparent that it escaped all search for decades. Nevertheless, if we keep these warning instances in mind, and remember how thoroughly bacteriologists have taken them to heart, we must still agree that really ultra-microscopic organisms do exist

Those hitherto "discovered", if that word may be used, are parasitic; but it remains to be seen whether similar organisms may not exist which are non-parasitic, and which perhaps lay the chemical foundations for all higher forms of life. However that may be, these recent discoveries in parasitism have required us to modify our ideas on the very interesting question — how small may a living organism be? It is now clear that life may be manifested in individual units which are so small that the number of actual molecules in them begins to be enumerable. And as our knowledge in this direction extends, the physico-chemical conceptions of life which satisfied most men of science in the nineteenth century seem to become less tenable than ever. But this is a field of inquiry so novel that we can as yet do no more than recognize its existence.

Having learned how general a fact parasitism is, extending from such large creatures as, say, the tapeworm, down to forms which no microscope can reveal, we should ask ourselves why this should be so. The answer is that parasitism solves so easily the chemical problems which face every living creature. In order to live, protoplasm re-

quires a constant supply of the particular elements and certain of the compounds of which it is made.

The parasite's aim — to live on ready-made food

These quite indispensable materials may, of course, be laboriously and honestly gathered, one by one, from their various natural sources. The process will tend to be a slow one, and at any time the sources may not be available. Obviously, there is a short cut, and that is to avail oneself of the collection and elaboration which some other living creature has already made. This convenient arrangement, with no disadvantages at all, we see in the case of many external parasites, such as the blood-sucking insects, which have lately become of such enormous importance to our understanding of disease, in consequence of the fact that they themselves have parasites, which they hand on to the creature they bite. The flea or tsetse-fly or mosquito lives conveniently by helping itself to a ready-made fluid, rich in nourishment, which the life of another creature has elaborated for its own purposes. Other parasites do better still, as in the case of that admirable product of natural selection, the tapeworm. This creature, which we may take as typical of many, benefits by its parasitism to the greatest possible extent. The body of its host provides it with warmth and shelter. It has no need of locomotion, nor of any kind of exposure. The flea or mosquito requires to digest the blood of its victim, but the tapeworm does much better. It takes up its abode in the bowel, just where the food reaches its fully-digested form, and it thus has available a plentiful supply of pre-digested food, which comes to it, and demands no effort whatever but that of receiving it.

The degeneracy of parasite always in proportion to its dependence

A universal rule of parasitism is that the degeneracy of the parasite is in proportion to its dependence. Thus, in physical terms, at any rate, there is little degeneracy to be observed in the mosquito, which has to fly, to bite, to digest. But the tapeworm has to do practically nothing, and so all its organs degenerate, except those of reproduction. It loses its means of locomotion, its senses, its power of digestion, and so forth; these are not called for; it has chosen an easier way of life, and they disappear accordingly. This can scarcely be called a case of the struggle for existence The tapeworm produces no poisons, and the body makes no attack upon it.

The struggle between poisonous parasites and substances that defend the body

But with yet other parasites the case is very different. These are typified by the parasite of malaria, which is an animal, and that of consumption, which is a plant. Here the struggle for existence is genuinely illustrated. Originally, of course, we are to imagine no animosity on the part of the parasite towards its host. It is merely trying to avail itself of an abundant source of nourishment. In the course of doing so, however, it produces substances, commonly called toxins or poisons, which happen to be noxious to its host. The host therefore tries to protect itself, by producing substances which will kill the parasite; and thus a struggle for life begins. It is this struggle which we see illustrated only too often, and which we call disease. The details vary widely in different cases, but this is the essence of nearly all of them.

Parasitism being the general fact of the living world that it is, we must be prepared to find that animals and vegetables alike have parasites, and that these may themselves be animal or vegetable. At one moment you may be spraying your throat with an antiseptic, and at the next your rose-bushes; and in each case your object is to kill parasites. In the case of mankind the parasites first known were, of course, the biting insects. Then we discovered other animal forms, living within the bowel, though some may live, during part of their life-cycle, in other organs, such as the muscles and the liver. Much later, thanks to the chemical study of fermentation and the improvement of the microscope, we found a variety of vegetable parasites, far commoner and more important than any known animal parasite, internal or external.

Animal parasites which, like vegetable parasites, are dangerous to the body

While the greater number of diseases could be accredited to these minute plants, only one case was known where a minute animal played a similar part. This was the case of the parasite of malaria, discovered by Laveran, a French army surgeon, in the year 1880.

Within recent years, however, the number of these minute animal parasites has been greatly augmented. Syphilis, for instance, is due to one, so that they can already claim two of the most important of all diseases. A terrible form of dysentery is also due to an animal parasite, of the class of amœbæ, known as the *amœba dysenteriæ*. Still later, a new genus of animals has had to be recognized as parasites, causing the various forms of disease called "trypanosomiasis", after the parasite, called "the trypanosoma". But there are many different forms of trypanosoma, whose normal habitat is the blood of many creatures besides man, and that which causes sleeping-sickness in man is only the most important.

Parasitism a lazy acceptance of "most life at least trouble"

We are clearly to understand, then, that parasitism is not only a relation between an animal on the one hand and a vegetable on the other. It occurs in all possible ways: and we know no form of life, animal or vegetable, which is wholly immune from parasitism. We think of many insects as parasites, and so they are, but the insects are themselves subject to parasites, like the lamentable infections which attack bees; and even parasitic insects like the malarial mosquito are themselves the hosts of the animal parasite with which they later infect man. And in the blood of worms or fishes we find parasites in just the same way. Similarly, it may be said that almost every form of life can be persuaded to become parasitic under suitable circumstances; it will always be glad to accept the most life at the least trouble.

Every parasitic species has taken to this mode of existence somehow. If we could trace its line far enough upwards, we should find non-parasitic ancestors at the head of it. But to this rule — that species in general can be persuaded, only too readily into parasitism under suitable circumstances — the green plants, taken as a whole, are the honorable exception. In virtue of their chlorophyll, as we may remember, they have direct access to an endless source of energy in the form of the sunlight which pours down upon them; and under favorable conditions their growth merely becomes more luxuriant and abundant.

Green plants which live as parasites at the expense of their fellows

But even here there are certain striking exceptions. No green plant is parasitic upon animals. We have quite enough to fear from the vegetable world, but only from the fungi. Certain green plants are, however, more or less wholly parasitic upon other plants. The general rule is that they germinate in the ground, often with some honest roots of their own, by which they obtain the salts in the soil-water, but also with a root in the underground portion of their host. Several plants, such as the eye-bright, have small green leaves of their own, so that they are only partly parasitic. Others, such as the broom-rapes, have really lost all their chlorophyll, and are wholly parasitic but for the fact that they have some roots of their own. The dodder, after twining round the stem of its host, into which it sends sucker-like branches, dies at its own root, and thus ceases to have any connection with the ground. The sucker-like branches, which are modified roots, serve all its purposes at the expense of its host.

Parasite specimens of plant and animal life up to the man who "sponges"

The mistletoe is in part a parasite, but by no means wholly so, for it has green leaves, and therefore is able in large measure to feed itself. The ivy, though often thought of as parasitic, is not so at all, having green leaves and true roots of its own, and merely using trees, as it would use a wall, for purposes of support.

Among flowering plants, perhaps the most striking and thoroughgoing parasite is the rafflesia, discovered by Sir Stamford Raffles in Java, nearly a century ago. It has no foliage leaves at all, and grows on the trailing stems of a vine, producing a huge flower some two or three feet across, at the top of a short root which penetrates the stem of the vine.

The recently discovered microscopic forms the most important of animal parasites

By far the most important animal parasites are those microscopic forms which have only lately been discovered. The number of parasitic animals decreases rapidly as we ascend in the evolutionary scale, as might be expected. The many parasitic worms have already been referred to, as also the parasitic insects. But among vertebrates only one class, Cyclostomes, is parasitic, these being best represented by the hagfish, or borer. This fish is to be found where the cod abounds, and it lives by penetrating into the body of the cod, and feeding upon its flesh. Nominally and technically, no parasites are to be found elsewhere in the whole great scale of vertebrates; but, psychologically and actually, we all know that the universal tendency towards parasitism is exhibited in not a few members of our own species, and that the universal penalty, which is degeneracy, is always exacted of them.

Though parasitism is so widely distributed throughout living nature, its presence does not always connote the existence of disease on the part of the host. On the contrary, just as we are the hosts of many microbic forms of life which do us no harm, so we find that parasitism elsewhere in most instances causes no serious injury to the host.

The way in which animals accommodate themselves to parasites

This is what we should expect to find under long-standing conditions, where evolution has reached a kind of stable state. Obviously, a parasite which exterminated the host upon which its own existence depended would itself become extinct; and that may have often happened. It is by no means to the interest of the parasite to destroy its host, any more, indeed, than that its host shall destroy it. The best arrangement for the parasite is one of equilibrium, in which it is tolerated by the host; and that means that the host ceases to suffer, or to suffer appreciably, from the presence of the parasite.

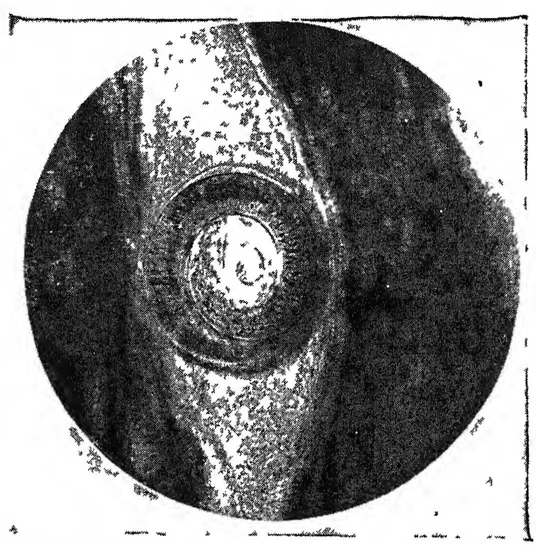
If, now, we study the facts in some country where the conditions have long been constant, where man has neither exterminated old species nor introduced new ones, nor domesticated wild forms and introduced them to an abnormal mode of life, we find the state of balance just described. Numerous parasites will probably be found in the blood and tissues of the wild animals. These may resemble, or be even identical with, parasites which we ourselves or our domestic animals have reason to fear. But under the natural conditions they do no harm, for a state of equilibrium has been attained. Their hosts accommodate them, but thrive in spite of them. The question arises — how has this adaptation been achieved? The answer to it is very important, for it will guide us as to the prospects of any new species, such as ourselves or our horses, which propose to settle in the district.

Theories of how immunity from the parasite it harbors is reached by the host

One view is that, by a steady process of natural selection, carried on through many generations, the host has reached a state of immunity to harm from the parasite which it harbors. Susceptible individuals have been persistently exterminated; while those which happened to vary in the direction of resistance would survive, and transmit their advantage to their offspring. In course of time there would thus be evolved an immune race, but its immunity would be by no means shared by any newcomers who had not been through the same discipline. This is one interpretation, of which the chief exponent, for many years, has been Dr. Archdall Reid, himself born in and long a resident of India. But the problem is exceedingly complicated, and other interpretations are possible. Thus, the state of balance and immunity on the

part of the host may have been reached because, in the course of generations, those strains *of the parasite* which were most deadly have exterminated themselves by the destruction of their hosts, while those which were less ruthless have spared the host, and have thus survived. In other words, the evolution may have occurred in the parasitic species, and not in the host species at all.

A third explanation, which may be called Lamarckian as against the former, which are Darwinian in principle, is that the individuals of the host-species have personally acquired some degree of resistance to the parasite, involving a profound and general modification of their body chemistry, and this "acquired immunity" has been transmitted to their offspring The thoroughgoing Darwinians deny, *in toto*, the possibility of any such thing, on a variety of grounds which are quite arbitrarily laid down It may be the true explanation, after all. In any case, the problems involved in this connection concern the future of mankind in the most intimate way.



A PARASITE ON MAN — *TRICHINA SPIRALIS* ENCYSTED IN MUSCULAR TISSUE

The control of the tropics, the mastery of disease, the spread of civilization, the ultimate total numbers of the human population of the earth and the proportions thereof contributed by the various races — all these largely depend upon the problems of parasitism. Thus, to take a familiar example, we speak, or used to speak, of a certain part of Africa as the "White Man's Grave", because of the liability of white men to fall victims to malaria there. If we examine the children of the natives in such regions we find their blood swarming with malaria parasites. They do not suffer as we do. Assuming that the parasite must remain (though in many instances the problem can be abruptly solved by the extermination of the parasite) we have to decide whether, and, if so, how, the white man can reach the immunity enjoyed by the native; and we have also to decide whether this is really an immunity worth having, or whether, in point of fact, the native race is not degenerate, the victim of racial poisoning through generations of parental malaria, as Sir Ronald Ross believes.

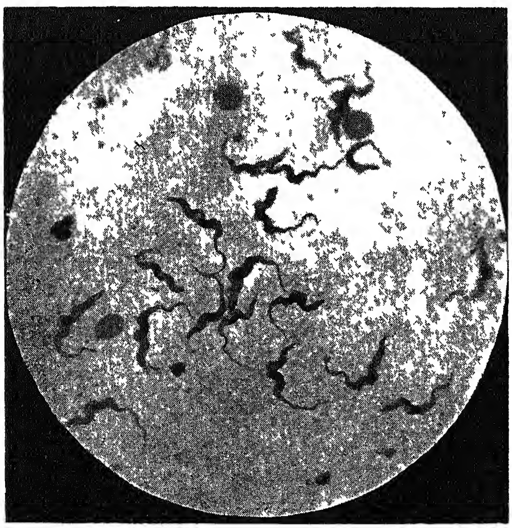
In cases where the parasite can be exterminated by man, a new factor in evolution, which identifies it, and destroys its breeding places, no further problem remains. But in many instances man cannot do so — at any rate, yet; and the question arises — what is he to do? Sharp controversy will now arise between the exponents of the various interpretations which we have just looked at The pure Darwinians, strenuously teaching what Darwin repudiated, will argue that only natural selection by the parasite will produce immunity against it In the case of tuberculosis, for instance, which we shall shortly have to consider in detail, they say that medical science and philanthropy can only interfere with the sole means by which a race may acquire immunity to a disease — namely, by the gradual elimination of the most susceptible. They argue that in this way alone can a race be made strong; while the Lamarckians argue that in this way it will be made weak, owing to the cumulative action of the disease-poison upon successive generations. These are differences which in fact, cannot be resolved upon paper, for it all depends upon what we begin by assuming; and they require exact observation as to what actually happens in nature itself.

But in any case it is true that the facts of parasitism play a very large part in evolution, and in the distribution of living forms. To take our own species as simply one among millions, evidently its geographical distribution has depended in the past, and depends at the present moment, upon the distribution of certain parasites. Where they abound, man is absent, or is found in only very small numbers. Mere physical conditions trouble him little. He penetrates everywhere, as all species try and tend to do, but the barriers which he cannot penetrate are those set up by parasites which would destroy him Within those barriers there may exist certain small numbers of men, either degenerate or else specially adapted, and resistant within limits, but a non-adapted race cannot pass them without heavy penalties. On the other hand, members of the race within the area of parasites may be removed, and then multiply amazingly, like the negroes in the United States. What is true of man is true of many other species of animals and plants. If we examine their distribution and its limits we find that they are determined by the presence, beyond those limits, of creatures which would become parasitic upon them. Under the conditions of nature, things have mostly adjusted themselves. Perhaps a species has become resistant, in any or all of the ways we have discussed. Or else the species simply does not occur where the parasite or the potential parasite occurs.

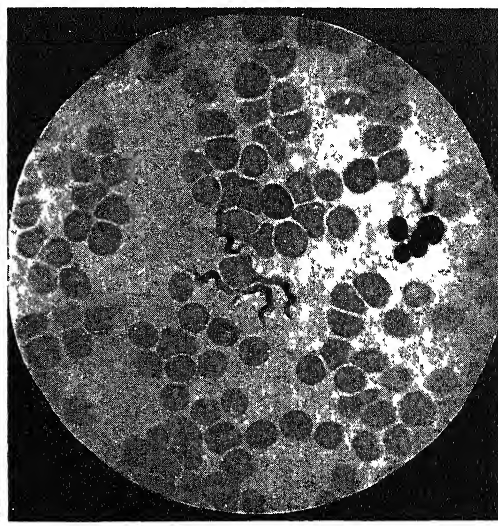
On the whole, then, the fact of parasitism does not connote any appreciable quantity of disease in a state of nature The internal characteristics of species, host and parasite, and their distribution, are so evolved that, in general, disease exists to only a very small degree.

But this we begin to appreciate only when we observe the consequences of any interference with the existing adaptation. We modify our own conditions, as in the formation of great urban aggregations, and promptly find ourselves the victims of many parasites. We penetrate to places where our race has undergone no evolution — Darwinian, Lamarckian or other — and again the result is disastrous. We take our horses with us to serve us, and find them the victims of an infection, transmitted by a blood-sucking fly, to which the native animals are practically immune. Just the same happens with many of the plants which we desire, and introduce into novel situations.

The work of the last few years, beginning with the labors of Sir Patrick Manson and Sir Ronald Ross, now a long time ago, has given us a general picture of parasitism



TRYPANOSOMES TRANSMITTED TO HORSES AND CATTLE BY TSETSE FLIES



TRYPANOSOMES OF SLEEPING SICKNESS TRANSMITTED TO MAN BY A BITING FLY

which may apply to many cases hitherto obscure. First demonstrated in the case of a kind of malarial infection in birds, it is now seen to be a fair statement of a practically world-wide state of things. We have seen that the animal kingdom may be subdivided into two great parts, the invertebrates and the vertebrates. These latter culminate in the mammals, and more especially in man. At the head of the invertebrates we find a vast variety of insects. The struggle for existence, and for the possession of the world, is largely seen to resolve itself into a curious contest between certain of these insects and man himself. But it would be no contest worth mentioning if the insects were merely parasitic upon the blood of man and no further complication existed. In that case the insects would be no more than inconveniences. Fleas are a nuisance, but they do not actually limit the distribution of the human species, or keep down its numbers; or, at any rate, fleas do not in this country. The loss of a little blood, to feed so small a creature, really does not matter.

The world-problem depends upon the fact that the parasitic insect is itself the prey of parasites. The insects which are not, such as fleas in this country, do not matter for evolution. They are merely a nuisance. But many insects matter immensely for the future distribution and quality of life upon our planet, not merely because they are parasitic upon man and other vertebrates, but because they are themselves the hosts of parasites which occupy a place very low down in the animal scale or sometimes in the vegetable scale, as in the case of the bacillus of plague. The insects distribute, in various ways, the parasites which invade them. In some cases, as we shall see, the insect is merely a vehicle, not essential for the maintenance of the life of the parasite. Such seems to be the rat-flea in conveying the bacillus of plague from the rat to man. But in other cases the vital relations are much more complicated, for the minute parasite requires to pass a necessary part of its life-cycle in the body of the insect, and another part in the body of the mammal that the insect bites. This parasite thus becomes the instrument with which the insect wages against man, or animals valuable to man, the fight for the possession of the world; and upon the solution of these problems, as we shall see, depend the hygiene and the destiny of the tropics.

Thus from the biological problem of parasitism in general we pass to the special problems of the conquest of disease, in so far as that depends upon parasitism. Close acquaintance with parasitic disease has taught us that it is largely a matter of chemistry — the special chemistry of the parasite and of the host, and the relations between them. Given sufficient knowledge of chemistry and of the special biology of the parasites, problems of disease thus become soluble. In surprising but unequivocal fashion they are removed from the sphere of the doctor. He may study his patients and their symptoms with infinite assiduity, but he will never be any nearer the understanding of the causes some of the results of which are all that he can detect. His experience, his stethoscope, his skilled touch, trained eye, everything characteristically medical about him, including his knowledge of drugs and of the art of prescribing — all these are set aside. The greater part of all disease is seen to be not a medical problem at all.

Medicine, which is literally the business of healing, may be allowed to rule in the actual care of the patient, but the essential problems, the solution of which will make all medicine by so much superfluous, are not medical at all. They are biological and chemical — any number of lifetimes of clinical experience would leave us where we were in regard to them.

When we look backwards we see that our knowledge dates, on the whole, from a single man, who never held a medical degree, but was essentially and originally a chemist; but he carried his chemistry to such lengths as ere long made him the greatest doctor of all time, the father of preventive medicine. In due course this chemist, Louis Pasteur, became a master of a great province of biology; and as such he falls to be considered now, at the beginning of our study of the conquest of disease.

DISEASES OF GARDEN PLANTS

Common Maladies of the Potato, Tomato, Bean, Beet, Lettuce, Cabbage and Onion

METHODS OF PREVENTION AND ERADICATION

PRACTICALLY every wild and cultivated plant is injured to a greater or less degree by one or more parasitic organisms. The diseases which result are, however, in some cases of so little importance that the vigor of the plant is not impaired. Cultivated crops are usually diseased to some extent, but often the resulting financial loss is insufficient to warrant the expenditure of time and money for its prevention. In other cases the same or a different disease may involve the total loss of the crop. Weather conditions play an important part in determining the seriousness of plant diseases. Rainy periods are usually followed by destructive outbreaks of certain maladies, due to the fact that the presence of abundant moisture favors the rapid development of the parasite. In one season, for this reason, a given disease may be very destructive, while in the next practically no trace of it may be found. One week a field or garden may present a healthy appearance, and the next week half the plants may be ruined. A large element of chance enters, therefore, into the raising of most plants. The wide-awake, modern grower may, however, insure himself against serious loss by using standard methods of prevention.

Few plant diseases caused by fungi or other microörganisms can be cured after the plant has actually become affected. The entrance of the parasite into the interior of the plant can, however, usually be prevented. Fungicides are used primarily to prevent injury rather than to cure that which has already taken place. In this respect the treatment of plant diseases differs radically from that in vogue in the treatment of disease in man. In reality the fungicide serves as a protecting armor to the plant; but in most cases after the fungus has gained an entrance it is then too late and absolutely useless to apply the fungicide. In a few cases, in which the fungus is normally largely external on the host, such as the powdery mildews of roses, hops, lilacs, cherries and other plants, dusting the affected portions with sulphur will kill the organism and restore the host to health.

Not all methods of disease control have to do with the application of fungicides. Pruning out of affected parts, various types of seed treatment, soil sterilization, crop rotation, the application of various substances to the soil, drainage, the complete eradication of alternating host plants, the destruction of insects carrying the disease germs, the planting of immune or resistant varieties of host plants, and exclusion of diseased plants from a given territory by federal or state inspection or quarantine constitute some of the other remedies.

The implements for combating plant disease should be always on hand and in condition for use, and the application of a spray on short notice should be possible. No grower who hopes to obtain clean crops should trust to chance. He should have always available the means for fighting the many fungi and bacterial foes which are sure sooner or later to assail his plants. In the use of spray mixtures the owner of a small garden will find

it more advantageous to use the proprietary mixtures which are put on the market as fungicides than to attempt to mix his own materials. Large growers of any crop will, however, find it cheaper to buy the ingredients and prepare their own mixtures. Spray nozzles and other apparatus can be bought at any hardware store.

Diseases of garden crops annually exact a toll which aggregates in the country as a whole in any season an enormous total. If every gardener would combat the diseases which appear in his own small plot of ground a greatly increased production would be effected and the high cost of living would be proportionately reduced.

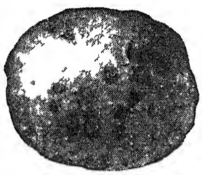
Some of the common diseases of the potato and their remedies

Since potatoes constitute so important a part of the diet of the American people, and because of their high price in recent years, it is especially desirable that disease in this crop be eliminated. The potato plant is subject to attack by a considerable number of parasitic organisms, and each year a new parasite seems to join the ranks or prove more destructive. The most serious disease of the potato is late blight caused by *Phytophthora infestans*. This organism and the disease which it produces have, however, been discussed at length in another chapter and need not be considered here. Another common disease of the potato is scab. This malady may be recognized from the typical disfiguration of the tuber, which shows slightly raised, irregular, corky scab spots on the skin. The lesions caused by this disease are wholly superficial. The inner lying tissue of the tuber is not penetrated, and the appearance and vigor of the plant above ground are not affected. The tubers are merely rendered unsightly and the price which they will command on the market is substantially reduced. For the elimination of this disease several measures looking forward toward prevention must be carried out. Tubers apparently undiseased should be selected for seed. They should then be soaked before cutting for two hours in a formalin solution made by diluting one pint of formalin in thirty gallons of water. Only clean soil should be used; soil which has previously been planted with potatoes should be avoided. The application of lime or wood ashes to the land is very undesirable. Since an alkaline soil is favorable to the parasite "souring" by green manuring or plowing under of a green crop such as clover is recommended. When very large lots of potatoes are to be planted soaking the tubers in formalin involves such an enormous amount of labor and so many receptacles that the method meets with disfavor among growers. In the search for a more satisfactory method of seed treatment gaseous disinfection suggested itself, and experiments were carried on with several gases, among them the fumes of sulphur. Formaldehyde gas obtained by the evaporation of formalin has, however, proved the most effective. This method may be briefly outlined as follows.

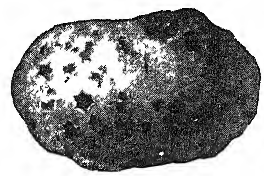
Simple directions for making an effective disinfecting chamber

It is first necessary to have a perfectly air-tight disinfecting chamber. For this purpose a room in a barn may be partitioned off, and the floor, side walls and ceiling covered with an air-tight coating of builders' paper. Slatwork crates having a capacity of about two barrels are recommended for holding the tubers while they are being treated. These should not be over nine inches deep. The crates may be arranged in vertical tiers in a framework made by erecting 2×4 scantlings as uprights and nailing upon these 2×2 cross pieces for supporting the crates one above the other. They should be arranged in such a way that the crates may be pulled out as the drawers from a cabinet. There should be abundant space at the back and sides, and between the bottom of one crate and the top of the next crate beneath to allow for free circulation of the gas on all sides. In the center of the room there should be an open space, preferably a wide aisle, to facilitate the filling and removal of crates and to leave room for the generation of the gas.

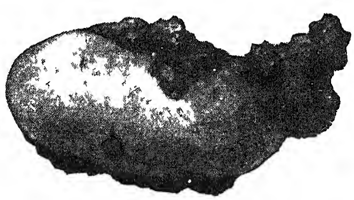
For a generator a small galvanized iron wash-tub about 15 inches in diameter may be used. On account of the heat evolved in the generation of the gas an earthenware receptacle is unsatisfactory, and a shallow vessel is to be avoided since there is considerable danger of the contents boiling over on to the floor. The generator should be placed in the center of the room on the floor or elevated somewhat on a box or stool. When ready to generate the gas a quantity of crystals of potassium permanganate should be sprinkled evenly over the bottom of the tub. Then the formalin should be poured over these, and the tub given a rapid tilt to insure wetting all the crystals. The operator should then retire quickly from the room, closing the door tightly from without. For every 1000 cubic feet of space in the room 23 ounces of potassium permanganate and 3 pints of formalin should be used. The room should remain closed for 48 hours and since the gas has a very corrosive effect on the mucous membrane of the nose and throat the operator should avoid breathing it. After the room is opened, considerable time should be allowed for the escape of the gas before an attempt is made to enter. When first mixed the potassium permanganate and formalin show little change, but soon a violent foaming and boiling is set up and the formaldehyde gas is liberated. The materials employed in this process are not expensive, and the gas necessary for 1000 cubic feet of space may be generated for about three dollars. The expenditure of many times this much money would be a good investment, considering the amount of the losses which a grower suffers from this disease.



Common "scab" of potato disfigures the surface but does not affect the inner tissues of the tuber.



"Powdery scab" of potato The dark pustules contain the spore powder of the slime mold, *Spongospora Solani*



The dread "black wart" disease of the potato which has spread rapidly through Europe

A rot of the potato caused by "late blight"

Porter Bulletin 1, University of Wisconsin Agricultural Experiment Station

COMMON DISEASES OF THE POTATO

Several other diseases of the potato cause excrescences over the surface of the tuber. Two of these, the powdery scab and black wart, are more serious than common scab since the tuber suffers more pronounced malformation. Neither of these diseases is as yet common in this country, and the federal quarantine board is using every effort to prevent their spread throughout the potato-growing sections. If they become widespread they will be exceedingly destructive. The powdery scab is caused by a slime mold, *Spongospora Solani*, while the black wart is due to a fungus, *Chrysophlyctis endobiotica*. No very effective methods of control can be recommended for either.

A serious disease of the foliage of the potato is "early blight" caused by *Alternaria Solani*. This is a typical leaf blight and may be easily distinguished from the late blight previously described and from other pathological conditions of the leaf by definite characteristics of the lesions produced. The spots are brown, circular or oval, and distinctly marked with concentric lines like a target. They are scattered irregularly over the leaf but in severe infections may be confluent. The disease results in the early death of the leaves, and the vines dry up prematurely, resulting in the production of small tubers, and not infrequently in the loss of 50 per cent of the crop. Spraying of the plants with Bordeaux mixture will also control this disease. Early blight also appears on the tomato, jimson weed and other closely related host plants.

The tomato is not subject to attack by so many serious diseases as is the potato. In the United States it is, however, affected by two maladies worthy of note.

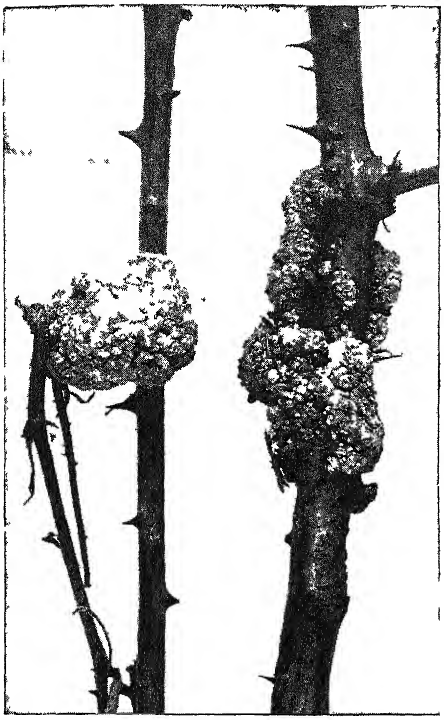
These are "blossom end rot" and "leaf spot". The former makes its appearance in the development of a spot at the blossom end of the fruit. This spot is accompanied by a characteristic dry rot and the lesion turns black. Unlike most plant diseases this one is not due to a parasitic organism. It is physiological in nature and induced by a too sudden checking of the water supply, or by too frequent watering. Another name applied to the disease is "œdema". It can be avoided by the use of proper methods of cultivation, which will insure for the plant a uniform supply of water throughout the season. Other similar physiological diseases are "stippen" of apples and œdema of cabbage and certain other plants.

LEAF SPOT OF TOMATOES
1, leaf attacked by fungus, 2 and 3, magnified portions of diseased leaf, 4 section through leaf showing fruiting conceptacle magnified, 5, spores of the fungus, highly magnified

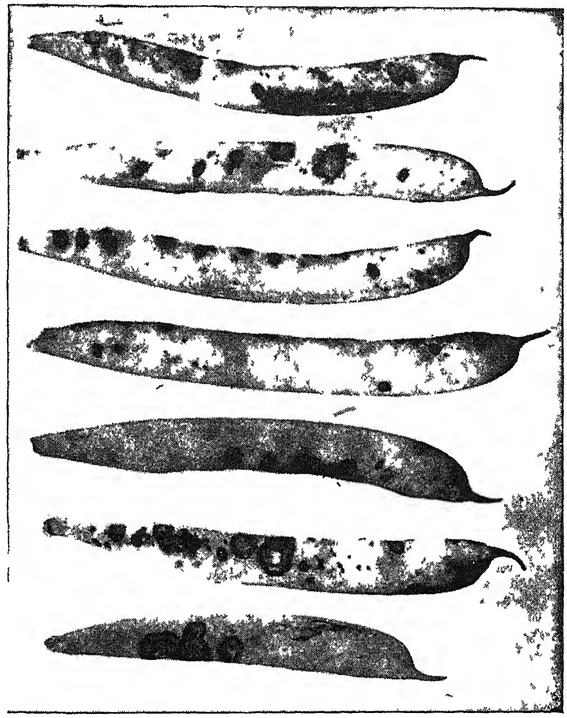
Leaf spot of tomato is a destructive foliage disease, due to a fungus, *Septoria Lycopersici*. Numerous definite, small, angular spots with pale centers and colored borders appear on the leaves. Petioles and twigs may in severe cases be also affected. The leaves curl up, die and fall off. The disease may be recognized by the fact that it makes its appearance first on the lower leaves and works upward toward the top of the plant, killing the leaves in turn as it advances. It can be controlled only with great difficulty since the fungus passes the winter in the old dead leaves which fall to the ground. When setting out plants it is desirable to pinch off all the lower leaves that might touch the ground, and also all those which bear spots of any kind. These should of course be removed and burned. If the plants are sprayed very thoroughly on the under side of the leaves every week or ten days with Bordeaux mixture of the 5–5–50 formula the disease can be greatly reduced.

Three serious and widespread diseases of the common garden bean cause great loss to the growers of this plant every year. Of the three, anthracnose is certainly the most destructive. Some growers speak of this disease as "rust". It is not, however, a true rust, since the fungus concerned, *Colletotrichum Lindemuthianum*, is a member of a widely separated group. The disease may be recognized by the presence on the pods of unsightly depressed spots These appear at first as small brownish or purplish areas of discoloration. Later, with the increase in size of the spot, the center becomes depressed and masses of pink spores are developed at its center. The fungus also attacks the stems, leaves and cotyledons but it is most conspicuous on the pods. The disease is carried over the winter in affected seed. Only clean seed obtained by selecting clean pods should be used for planting. The sorting of seed fails to control the disease because the fungus may be present in seed which to the eye appear clean. A pod which looks clean, however, never contains diseased seed Seed treatment, moreover, is ineffective Careful spraying of the plants with Bordeaux mixture, 5–5–50, will reduce the amount of the disease. Three applications of the spray should be made during the growing season, the first when the plants break through the ground, the second when the first pair of leaves are fully expanded and the third when the pods begin to form. A hand sprayer should be used and the plants thoroughly covered.

COMMON DISEASES OF GARDEN PLANTS



Raspberry canes, showing large excrescences caused by the "crown gall" organism, *Bacterium tumefaciens.*

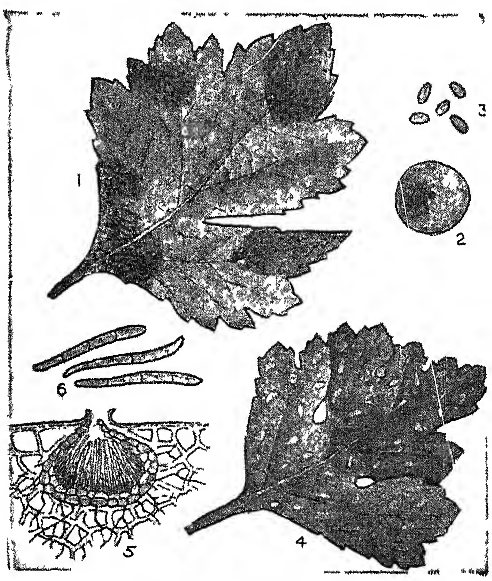


"Anthracnose" of beans. Pods showing prominent lesions due to the presence of the anthracnose fungus, *Colletotrichum Lindermuthianum*

A lettuce leaf showing prominent disease spots caused by *Marssonina Panattoniana.*

"Club root" of cabbage. A young plant with the roots diseased and hypertrophied due to the attack of *Plasmodiophora Brassicæ,* a slime mold.

Bean blight is in some localities more destructive than anthracnose. It is of bacterial origin, the causal organism being *Bacterium Phaseoli*. This disease also is extremely difficult to control. The organism probably hibernates in the seed. The planting of clean seed from clean pods, and the application of the three sprays of Bordeaux mixture as for anthracnose will reduce the grower's losses, but no wholly satisfactory control measures have been evolved. With favorable weather conditions the disease is very destructive. It affects chiefly the leaves, causing large dead brown areas



LEAF DISEASES OF CELERY

1, celery leaf spot, 2, and 3, perithecium and spores, highly magnified; 4, septoria on celery-leaf, 5, section of perithecium of septoria embedded in a leaf; 6, spores of septoria, highly magnified.

The pods, however, frequently show spots not unlike those caused by anthracnose.

Another serious disease of the bean is caused by a soil fungus of the genus *Rhizoctonia*. This organism attacks the plant in the soil and causes a rot of the stem just at the surface of the ground. Depressed shriveled areas of a reddish brown color are formed. If the plant is very young when attacked, damping off may result, and at any age the weakening of the stem makes more likely the breaking over of the plant. In the roots an extensive dry rot may develop and the small lateral roots be destroyed.

Other plants attacked by Rhizoctonia are sugar beet, carrot, cabbage, cauliflower, cotton, lettuce, potato, radish, sweet potato, pumpkin, water-melon and pea.

The common garden beet and the sugar beet are affected by several diseases. Of these the leaf spot caused by the fungus *Cercospora Beticola* is the most widely distributed and the most destructive The leaf spots are at first small brown points with reddish purple borders. Later when they reach a diameter of 4 mm or more the center becomes almost white On these spots long filamentous, many-celled spores are formed. These are blown to other plants, or, falling to the ground, are able to retain their power of germination for months The diseased plant presents a characteristic appearance in the field, the crown of the plant being considerably more elongated in a vertical direction than is normal. The leaves blacken and dry up gradually from tip to base and as they become dry they stand more nearly erect. Spraying with Bordeaux mixture will control the disease and since the spores hibernate on the ground early spraying is essential.

Lettuce is attacked by damping off fungi such as Rhizoctonia and *Pythium Debaryanum;* and is also affected with several more specialized diseases of which "downy mildew of lettuce" and "lettuce drop" are the best known. The downy mildew of this host is caused by *Bremia Lactucæ*. This disease is not infrequent when lettuce is grown in greenhouses, and it may occur in the fields in cool weather, particularly in the autumn. The frost-like growth of conidiophores appears first on the under side of the leaf. The affected areas then turn to a paler color, and the leaf soon wilts. The disease may be easily controlled in the greenhouse by supplying the plants with a large amount of light and ventilation. A more serious disease of lettuce is "drop" caused by *Sclerotinia Libertiana*. The same fungus causes a similar disease in other greenhouse and garden crops, including cucumbers, rape, tobacco and many forced vegetables and bulbous plants. On lettuce the disease first

makes its appearance in the production of water-soaked areas on the stem and basal portions of the leaves. There may be also some slight production of mycelial threads of the fungus over the surface of the leaf, and on these minute black more or less globose bodies which are called sclerotia. The disease spreads rapidly, and ultimately the entire plant collapses and seems to melt into a shapeless mass of decaying leaves. This fungus is widespread and is one of the most serious greenhouse pests The disease may be controlled by steam sterilization of the soil to a depth of two inches or more. While the plants are growing the surface soil should be kept loose and dry. Another serious disease of lettuce in certain sections is a leaf spot caused by *Marssonina Panattoniana.*

Where onions are grown in any quantity this crop is frequently seriously diseased. Two diseases, "mildew" and "smut", occasion the greatest loss. The mildew caused by *Peronospora Schleideniana,* is also known to growers in various sections of the country as "blight" or "mold". There have been several serious outbreaks of the disease in America. The fungus is a close relative of the organisms causing "late blight of potatoes" and "mildew of lettuce". On the onion the disease appears in June or July and the grower will notice on the leaves while they are still covered by dew a peculiar downy appearance of a violet hue. This is caused by the layer of conidiophores of the fungus. The diseased plants wilt down rapidly and do not recover. A field of onions in which this disease has run its course looks as if it had been sprayed with boiling water. The young plants appear to be somewhat less susceptible than the old. If the crop is sprayed frequently with Bordeaux mixture after June 15, when the disease is beginning to appear, it can be controlled. Crop rotation is also advised. Old onion tops, in which the oöspores of the fungus hibernate, should be destroyed.

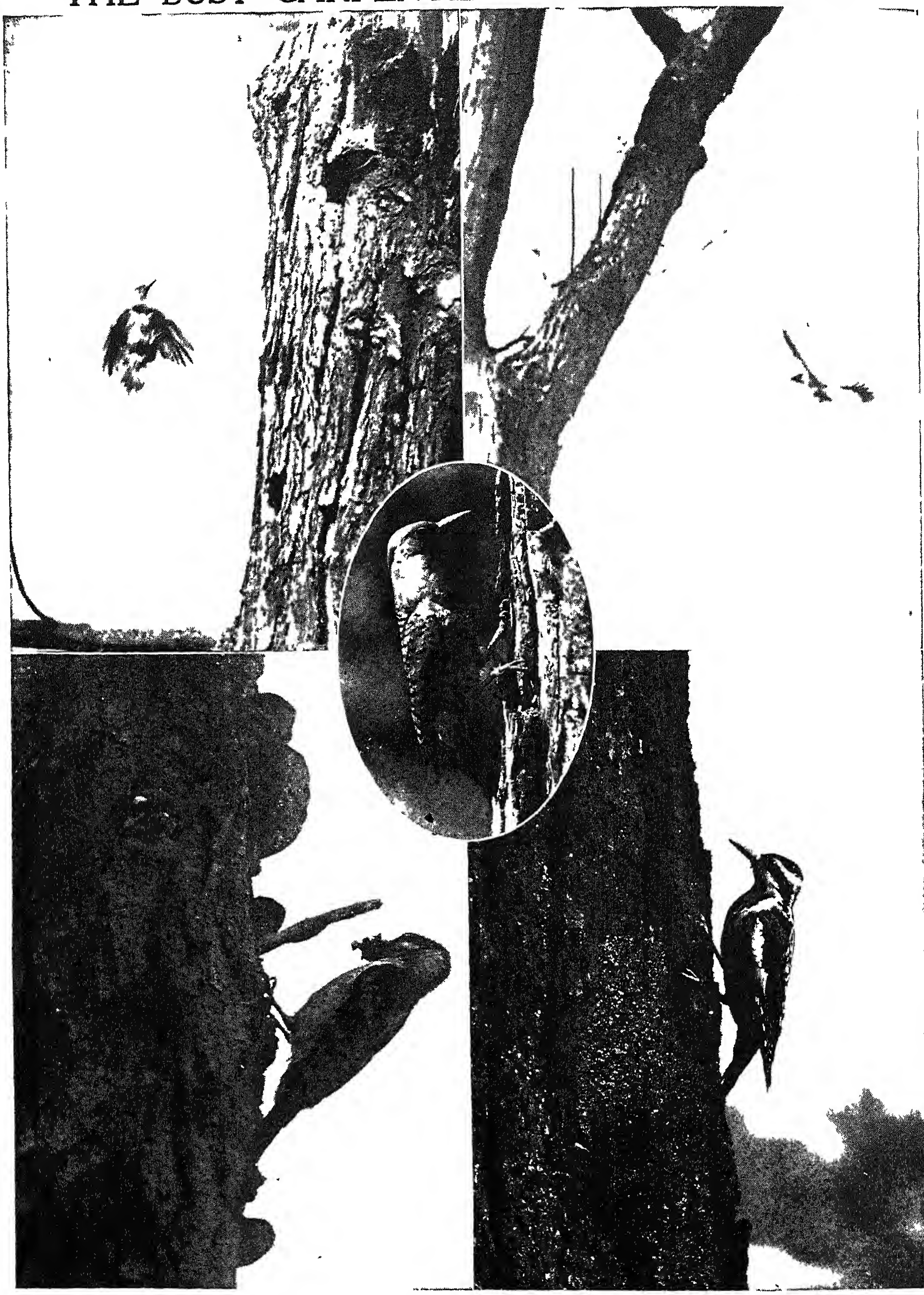
Onion "smut" has long been known as a serious disease of this host. Seedlings are attacked soon after the first leaf is formed, and dark spots soon appear on all the leaves. These spots become longitudinal rifts filled with black powder. Similar rifts appear on the bulbs. The powder is made up of a large number of spores in little aggregations called "spore balls". The fungus is closely related to the cereal smut fungi, and the black spore powder in the two cases is much the same in appearance. In the control of this disease seed treatment is useless, since the fungus lives in the soil. Onions should be set out in clean soil. Crop rotation

1, EUROPEAN, AND 2 AND 3, AMERICAN GOOSEBERRY MILDEW

should in so far as possible be constantly practised. In planting the seed a mixture of 100 pounds of sulphur and 50 pounds of air-slaked lime to the acre should be drilled into the rows. This will greatly reduce the disease.

Strawberries, raspberries, currants, gooseberries and others of the so-called small fruits are also frequently attacked by fungi. Every garden crop in fact has its diseases, and it has been possible in this limited space to describe only a few typical maladies on the more important.

THE BUSY CARPENTERS OF THE FOREST



FLICKER FLYING TO ITS NEST REDHEADED WOODPECKER FLYING TO NEST
FLICKER NEAR ITS NEST
DOWNY WOODPECKER WITH FOOD FOR ITS YOUNG YELLOW-BELLIED SAPSUCKER HARD AT WORK

The illustrations in this chapter except those on pages 3351 and 3353 are from photographs by A. A. Allen

OUR COMMON BIRDS V

Woodpeckers, Hummingbirds, Swifts,
Whip-poor-wills and the Nighthawks

THE BUSY CARPENTERS AND WEIRD NIGHTHAWKS

FEW birds are more easily recognized by the amateur ornithologist than are the woodpeckers. In spite of the fact that they constitute a large family (*Picidæ*) of over three hundred seventy-five species and are found over the entire world, except in Madagascar and the region of Australia, they are remarkably uniform in their habits and in their modifications. Indeed, some of the distinct and even strikingly marked species, like our downy and hairy woodpeckers, resemble each other almost feather for feather. Twenty-four of the nearly two hundred species of woodpeckers occurring in the New World are found in North America.

The typical woodpeckers have large heads with stout chisel-like bills which end in a narrow edge rather than a point, and are thus well suited for chipping wood. Their tongues are very long, capable of being protruded a couple of inches beyond the tip of the bill, and have recurved barbs at the tip. This combination of bill and tongue makes a perfect tool for drilling into the chambers of wood-boring larvæ and spearing the concealed grub. For this reason woodpeckers are considered one of the most valuable groups of birds.

The tail feathers of the woodpeckers are very stiff and pointed and serve as props to support the weight of the birds as they climb the trunks of trees in their characteristic manner. The tiny woodpeckers of South America and Africa, called "piculets", and the four species of wrynecks of the Old World, however, have soft tails without spinous shaft tips.

The feet of woodpeckers, likewise, are adapted to this climbing habit and differ from those of all the birds that we have thus far considered except the cuckoos in having two toes directed forward and two backward. Thus they serve as pincers for better grasping the bark. In a few species, the three-toed woodpeckers of northern North America, one hind toe has been lost.

Because of all these modifications, the woodpeckers are separated from the order *Passeres*, or "perching birds," and are put in an order by themselves, the *Pici*.

In color, the woodpeckers vary from the common black and white varieties, through various shades of brown and green, to those that are brilliant scarlet and yellow. In fact, patches of scarlet are found on the heads of the males of most species, even the most dully colored.

They are usually solitary birds and even the family parties disperse soon after the young are able to care for themselves. Our northern species, however, sometimes gather in scattered groups during the winter, often accompanying the flocks of chickadees and nuthatches, and regularly come to feeding stations maintained for them. In fact, they become so fond of suet that they continue to visit pieces hung in the trees all through the summer months, even when they drip in the sun and become rancid. They even feed their young with some suet and bring them to it when they are able to fly.

In nesting habits, also, woodpeckers are remarkably uniform, for they all drill holes in dead or soft-wooded trees and lay their eggs on the chips at the bottom of the cavity.

The size of the hole varies from about one and a quarter inches in diameter with the downy to two and a half inches with the flicker, and is correspondingly larger with the pileated and ivory-billed species. The hole is directed toward the center of the tree but a short distance and then drops downward for from six to eight inches to two feet and is usually enlarged toward the bottom for the convenience of the incubating bird. Usually both birds assist in drilling the hole and often carry the chips to some distance from the tree in order not to attract attention to it. The eggs are always glossy white and unspotted, but the number varies with the different species from four to twelve. There is one celebrated case of a flicker which continued to lay as often as the eggs were removed, until it had laid seventy-one eggs in seventy-three days.

Most woodpeckers excavate new nesting cavities each year, but some return to the same hole year after year, particularly the flickers and red-headed woodpeckers. Some make roosting holes for the winter or for the male bird while the female is incubating. In Europe several species of woodpeckers have come to use artificial nesting boxes put up for them, but in this country the flicker is, as yet, the only one that does so regularly. Other species will undoubtedly learn to do so as time goes on and as available dead trees become scarcer and nesting boxes more plentiful.

To be acceptable to a flicker, a nesting box should be from six to eight inches square inside, and from eighteen inches to two feet deep. The hole should measure two and a half to three inches in diameter and should be on one side, a couple of inches from the top. The inside of the box should be rough. The best place for the box is fifteen feet or more from the ground on the straight bole of a tree free from branches, on a dead tree, or on the top of a tree that has been cut off. Inasmuch as woodpeckers build no nests at the bottom of their holes, but merely lay their eggs on the chips at the bottom, it is necessary to put about two inches of sawdust or ground cork in the bottom of the box to keep the eggs from rolling around.

Woodpeckers have no true song and their call notes are inclined to be harsh and unmusical. In place of a song, the males, and possibly the females at times, have a loud rolling tattoo which they make by hammering with the bill upon a dead limb, a loose piece of bark, a drain pipe, tin roof or other resonant surface.

The most striking member of the woodpecker family in North America is the red-headed species, found from Ontario to the Gulf and from Colorado to the Atlantic, although for some reason it is rather rare in some localities, particularly in New England. Males and females are alike with the entire head red, the back and most of the wings blue-black, and the secondaries of the wings, the lower back and underparts pure white, giving them a most conspicuous appearance, especially in flight. The males of many species of woodpeckers have more or less red on the head, but no other has the entire head red.

Redheads are versatile birds in their feeding habits, and though they drill for their food less than the downy and hairy species, they often fly out after passing insects like the flycatchers, or get down on the ground in search of ants and worms like the thrushes. Occasionally individuals arouse the enmity of the whole bird and human world by eating the eggs or young of smaller birds. In the fall of the year their presence in a locality is largely dependent upon the supply of beechnuts, chestnuts or acorns, and at these times great disputes often occur between the redheads and the blue jays for the possession of certain nut trees and for a time such trees present a riot of color. Like the nuthatches, redheads often store nuts for winter use in the crevices of the bark or in fence posts. If the nut crop is good redheads are likely to pass the winter as far north as northern New York or Ontario, but otherwise they retire south of Maryland.

More abundant in most places than the redhead is the flicker, the only brown woodpecker in the United States. The flicker is known by various local names: high-hole or high-holder, clape, wickup, wake-robin, golden-winged woodpecker and over one hundred others. The flicker is about

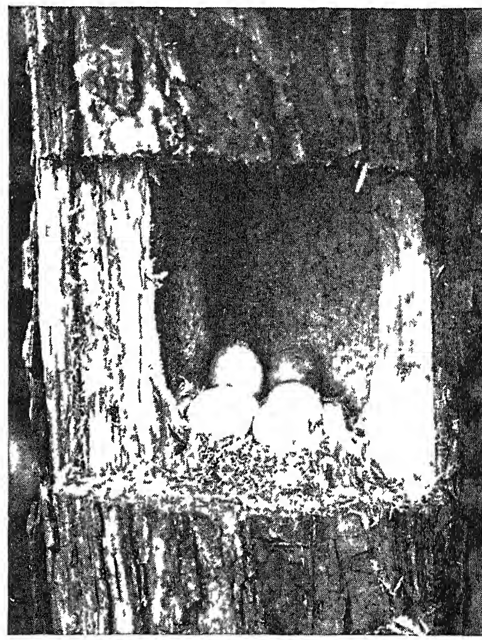
the size of the redhead, somewhat larger than a robin, brown above barred with black, light brown below spotted with black, and grayer on the head. Its most characteristic marks are a red crescent on the back of the head, a black crescent on the breast, a white patch on the rump and golden yellow lining to the wings and tail. The western flicker has this lining of the wings and tail red instead of yellow.

The flicker is a rather aberrant member of the family and now seldom drills for boring larvæ. Its favorite food is ants, which it secures by drilling into their nests upon the ground. Thus it is frequently seen hopping about lawns with the robins. Its bill is slightly curved and less chisel-like than most woodpeckers', and its tongue, instead of being barbed, has a sticky secretion poured upon it from the modified salivary glands which entangles the ants.

The downy and hairy woodpeckers are found throughout North America east of the Rockies, and are perhaps the best known of all the woodpeckers. The northern and southern birds have been separated into distinct races because of slight differences in size, but, to all appearances, the birds are the same. The two species are almost exactly alike, except for size, the hairy woodpecker being about the size of a robin (9.4 inches in length), and the downy somewhat larger than a sparrow (6.8 inches). Both birds are striped black and white above, and pure white below, about the only difference being that the outer tail feathers of the hairy are pure white, while in the downy they are barred with black. The males of each species have a crescent of bright scarlet on the back of the head, that of the hairy being divided through the middle by black. Both species are permanent residents where found, and often nest in the vicinity of the place where they are fed in winter.

Another familiar species of the Southern States, ranging as far north as southern New York, is the red-bellied woodpecker. It is a noisy bird about the size of the hairy, but with the whole top of the head red and with the back barred rather than striped. The red of the belly is quite inconspicuous. Like other woodpeckers, it is fond of suet.

The largest of all the woodpeckers is the ivory-billed species, a bird about the size of a crow, and fully as black, with a scarlet crest, a white stripe on each side of the neck, and large white patches in the wings. It was formerly not an uncommon bird in the larger forests of the South Atlantic and Gulf States but now is confined to the largest and most remote cypress swamps of the lower Mississippi Valley and Gulf States, where it is on the verge of extinction. It is a wild, shy bird, and cannot withstand the encroachments of civilization and the lumber mill.



"NEST" AND EGGS OF DOWNY WOODPECKER

Nearly as large and much more widespread, though confined to the forests, is the pileated woodpecker. It is similar in color to the ivory-billed, but has somewhat lighter underparts and does not have the white in the wings so conspicuous, or the ivory-white bill. The northern and southern forms of this bird range from Quebec to the Gulf, but it is nowhere a common bird. In the cypress swamps of Georgia and Florida, however, it occurs in numbers.

The red cockaded woodpecker is one of the less well-known woodpeckers of the South, found in the pine forests. It is similar to a hairy woodpecker in general appearance,

but has the back barred with black and white and has black streaks on its sides.

The three-toed woodpeckers, of which there are two species inhabiting the boreal regions and coming southward in winter to northern United States, are also about the size of the hairy, but have an orange-yellow patch on top of the head.

In the West are found the California woodpecker, which has the habit of storing acorns in holes which it drills in the bark of trees; the gila and golden-fronted woodpeckers, which resemble the red-bellied species; the Lewis woodpecker, the greenest of North American species; the red-naped, red-breasted and Williamson sapsuckers, which are similar in habits to the eastern yellow-bellied sapsucker.

The sapsuckers get the name from their habit of drilling rows of small round holes in the bark of many species of trees and drinking the sap which collects. One bird usually taps several different trees and each one in several places, and then makes the rounds as often as the sap collects. It is interesting to note that the barbs on the tongue, so characteristic of the woodpeckers, have been modified into a fringe or brush for collecting the sap. Sapsuckers eat likewise such insects as are attracted by the sap and, like the red-headed woodpeckers, are quite expert at catching insects on the wing. In addition they eat some of the soft inner bark exposed when the holes are being drilled, and, in soft-wooded trees, like the poplar, where the sap does not flow freely, and the cambium is almost gelatinous, they sometimes peck off fairly large areas. Ordinarily their rows of holes do not overlap and little or no damage is done to the tree, but sometimes, when the birds are very numerous, and for some reason persist in attacking a particular ornamental evergreen or mountain ash, they ruin its appearance, seriously weaken it or even kill it. The holes drilled by the sapsucker often stain the underlying timber, causing what are known as "bird pecks", and are said by lumber dealers to cause a devaluation to timber of the United States of nearly a million dollars annually.

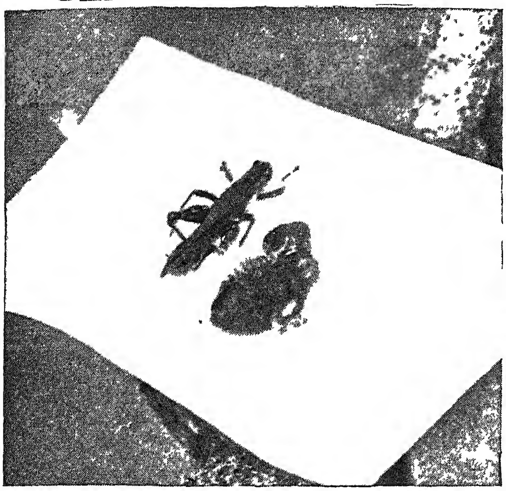
At times sapsuckers behave in an erratic and foolish manner, zigzagging through the trees with no apparent reason, flying into windows or walls on the sides of houses, even becoming so stupid as to allow themselves to be picked from the trees, or alighting on one's person and climbing up his leg as though it were the limb of a tree. It has been suggested that the sap ferments in the sun and that the sapsuckers become intoxicated, but this theory has by no means been proved.

The common sapsucker of the East is the yellow-bellied species. It is about the size of a hairy woodpecker with the same general appearance, but has the throat and the whole top of the head red. It has also a conspicuous white stripe on each wing, a black crescent on the breast, and slightly yellowish underparts which are somewhat streaked. The female has a white throat and immature birds have the top of the head black.

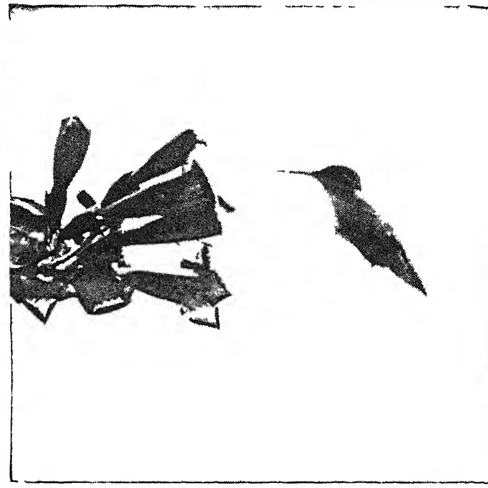
The hummingbirds

The smallest bird in the world is the "fairy hummingbird" found in Cuba. It measures two and a quarter inches from the tip of its bill to the tip of its tail and weighs but a fraction of an ounce. All hummingbirds, however, are not so small. Indeed, the giant hummingbird, inhabiting the higher peaks of the Andes, is over eight inches long and resembles a swallow. The majority of the five hundred and eighty species and sub-species, however, are tiny birds under four inches in length.

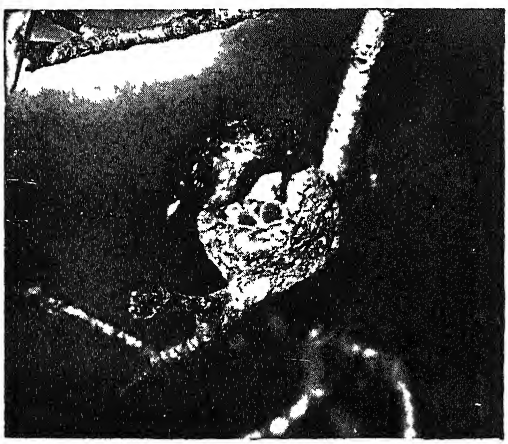
In addition to their small size, hummingbirds are noted for the brilliancy of their colors. "Glittering fragments of the rainbow," Aububon called them, and, indeed, each hue of the rainbow, from the most delicate blues and greens to the most vivid reds and purples, can be found on some species. Sometimes the extremes of color, in wonderful combination, are found on the back or breast of a single bird. The colors are not real pigment, however, but are caused by the refraction of light due to the structure of the feather, and appear brilliant only by reflected light. Thus even the most brilliant members of the family appear somber in many lights, and as they flit from flower to flower, they alternately flash and fade in ever changing beauty.



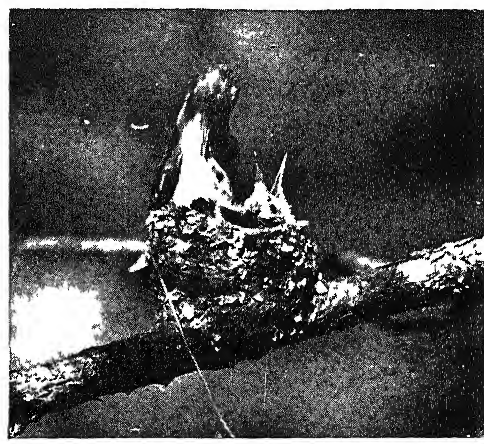
DAY OLD HUMMINGBIRD COMPARED WITH GRASSHOPPER



HUMMINGBIRD FEEDING AT TRUMPET VINE OR CREEPER



FEMALE RUBY-THROATED HUMMINGBIRD TURNING ITS EGGS



FEMALE FEEDING ITS YOUNG BY REGURGITATION

YOUNG RUBY-THROATED HUMMINGBIRD PERCHED ON A BLADE OF TIMOTHY

A HEAPING TEASPOONFUL — ADULT RUBY-THROATED HUMMINGBIRD AND NEST

Many species are curiously ornamented with elongate tufts of feathers about the head or breast. Other species have greatly elongate tail feathers four or five times the length of the bird, and these are sometimes enlarged at the end, or racquet shape. Still others have dainty little pantalets of fluffy white feathers about the legs.

In spite of their great variety and the abundance and the wide range of some species, hummingbirds are found only in the New World. They undoubtedly originated in the Andes of Colombia or Ecuador where the majority of species are still found, but some have spread as far as Patagonia and others as far as Alaska. They have never reached either Europe or Asia, however, and numerous attempts to introduce them have failed. The majority of species are quite local in their range, some being restricted even to a single mountain top or to a single valley. Again, although they are found all over North and South America, they are very poorly represented in some regions. Thus, while eighteen species have been found in the United States, only one species, the ruby-throated hummingbird, occurs east of the Mississippi. Some species live in the dark humid forest, others in the arid deserts, but the great majority spend their lives in the sunlit treetops or about clearings in the forest wherever there are flowers.

It is from the nectar of the flowers and the tiny insects lurking in the corollas that most species derive their sustenance. A few pick insects from beneath the leaves and a few others dart out after passing insects as do the flycatchers, but these are the exception. Indeed, so dependent are they upon the flowers that the bills of many species have become adapted to particular flowers. In all species the bill is probe-like and the tongue tubular for sucking the nectar, but in certain ones the bill has become very much decurved, even sickle-shaped, and in others even upcurved to help them in getting nectar from flowers having pouch-like or lip-like corollas. One species has a bill nearly five inches long and another a bill that measures scarcely a quarter of an inch. Curiously enough the two species feed at the same long tubular flowers, the one taking the nectar in the legitimate way, the other evading nature's provision for the cross-fertilization of the flowers by drilling a hole through the base of the flower into the nectary. Indeed, it is upon the hummingbirds that many of these flowers depend for cross-fertilization, the head or the bill of the bird carrying pollen from one flower to the next.

Even as wonderful as their tiny size, their brilliant colors, or their curious modifications, are the nesting habits of the hummingbirds. The nests are skilfully constructed of plant down or wool which is gathered from ferns or catkins, fastened together and to the branch by spider webs. The outside of the nest is ornamented usually with lichen or bits of moss so that it simulates a knot or resembles the branch upon which it is placed. Usually the nest is saddled upon a branch, but with some species it is regularly fastened to the underside of the large leaf of a palm tree fern or even to a projecting cliff or an overhanging rock. Invariably but two eggs are laid and these are always pure white without spots. They are about the size of beans, sometimes smaller, and always more slender.

The voice of the hummingbirds are seldom heard and it is the buzzing of their tiny wings that gives them the name. During the courting season, however, most species give vent to their feelings with excited chipperings as they swing, with flashing wings, back and forth past the female. A few species have songs of surprising volume and melody which they sing, as do other birds, from an exposed perch on the top of a bush or tree.

By far the best-known species is the ruby-throated hummingbird, found in summer throughout eastern United States and Canada as far west as Texas. The male bird is bright emerald-green above and grayish below with a patch of brilliant ruby-red feathers on the throat that are lacking in the female. Unless the light strikes the feathers at just the right angle, both the red and the green appear dark so that when the little bird is at rest, it is usually passed unnoticed. Indeed, one is led to believe that they spend their entire lives on the wing because they are so seldom seen when resting.

Rubythroats appear from the south, where they have been wintering from southern Florida to Panama, about the first of May when the leaves are just beginning to unroll and the first blossoms of the cherry and the flowering quince are beginning to open. From that time to the middle or the last week of May, the flowering trees sometimes buzz with their wings, for although they are not at all gregarious, a tree like a horse-chestnut at the height of its flowering season may attract them in great numbers.

About the last of May, nesting begins and the dainty little cottony structure is saddled on the branch of an apple or other tree from fifteen to twenty-five feet from the ground. The outside is covered with lichens which makes it very difficult to discover. Indeed, were it not for the alarm of the mother bird and the intrepid way in which she darts at one's head when in the vicinity of the nest, it would seldom be discovered. No bird or animal is allowed to approach within a certain radius of the nest without being attacked. Be it one of its own kind or one of the largest hawks, it is attacked with the same courage.

The male is at first quite attentive, but after the eggs are laid he disappears and never assists in the incubation or care of the young. Instead he selects some favored locality where there are flowers and when not making the rounds, sits quietly on a dead branch or telegraph wire preening his feathers. The eggs hatch after two weeks of care and the young remain in the nest for about three, at the end of which they buzz from the nest, nearly as strong as the old birds. When first hatched, they are blind and naked and their bills are very short. It is at this stage that one can more easily recognize their relationship to the swifts, which are so different in adult life.

Of the seventeen other species of hummingbirds that reach the United States, only seven advance beyond the states bordering Mexico. The best known of these is the rufous hummingbird, found in summer from California to Alaska, especially in the mountains. It is reddish brown in color, the male with a fiery red throat patch that shows orange and yellowish green in some lights. It is particularly fond of red flowers and if a person wears bright colors in the field, they often flash up to examine them.

The Swifts

Watching the chimney swifts as they dart back and forth over the housetops or circle in dark clouds before descending some disused chimney, one never suspects their relationship to the hummingbirds. Even close inspection fails to reveal much similarity except in the shape of the long narrow wings and the tiny feet. Nevertheless the kinship exists and much of their internal structure is very similar. As already intimated, if one examines the newly hatched hummingbirds with their tiny bills and large mouths or if one sees the large dull-colored giant hummer of the Andes, the relationship is better understood.

There are nearly one hundred species of swifts (family *Micropodidæ*) of which about a third are found in the New World. Of these but four occur in the United States and Canada and only one, the chimney swift, is ever found east of the Rocky Mountains. This bird is commonly called the "chimney swallow", and indeed it resembles a swallow much more than it does a hummingbird, although there is no real relationship between the two, the swallows being but modified passerine or perching birds while the swifts and the hummingbirds form a very different order.

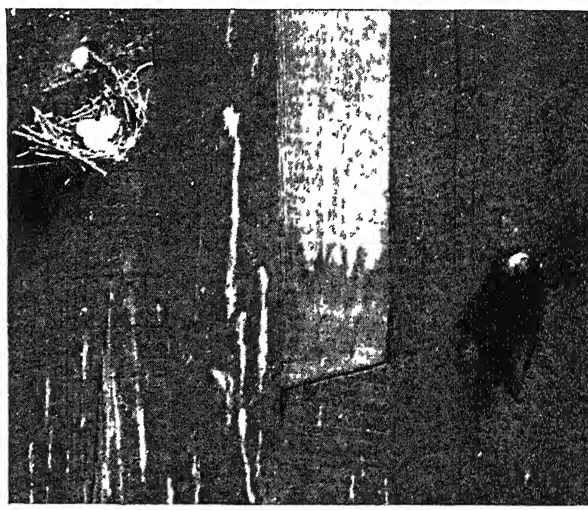
With few exceptions, swifts are sooty black birds, sometimes with white on the rump or under parts but often with no marks whatever. The chimney swift, for example, is entirely sooty and but little lighter below than above. The East Indian tree swifts are exceptions, in which the plumage has a metallic gloss and the feathers are quite silky, ordinary swifts having rather short harsh plumage.

The most interesting thing about the swifts is their method of nesting. The nests are built of sticks, straws, feathers or other material in the form of a shallow saucer, the materials being cemented together and to the wall of the cave, hollow tree or chimney by means of the birds' saliva, which is specialized into a peculiar glue.

In one group of swifts inhabiting the islands off the east coast of Asia, the nests are made entirely of this saliva It is from these nests that the famous "birds'-nest soup" is made, and the birds themselves are called the "esculent swifts". They nest in large colonies in caves and the gathering of the nests is an organized industry. The nests weigh about half an ounce and bring as high as seven dollars a pound The nests have been gathered from some caves certainly for over two hundred years, yet there seems to be no diminution in the number of the birds.

The nest of the chimney swift is built of short twigs which the birds break from the tops of dead trees either with their bills or feet as they swoop past without stopping. An area in the chimney or silo, as shown in the illustration, is first coated with the viscid saliva so that sticks will adhere to it. Others are then added and coated with the peculiar glue until a little saucer is constructed strong enough to support the weight of the bird, or even both birds, for they sometimes sit on the nest side by side. The nest is so small, however, that the young outgrow it long before they can fly and they have to climb out and cling to the wall as do the old birds, propping themselves up with their tails. The tail feathers are stiff and tipped with spines, somewhat similar to the woodpeckers except that there are no barbs at the tip and merely the shafts protrude. They never perch or descend to the ground as do other birds.

A YOUNG CHIMNEY SWIFT IN ITS "COAT OF MAIL"



A CHIMNEY SWIFT NEAR ITS LITTLE SAUCER OF A NEST OF TWIGS STUCK, AS WITH GLUE, IN A SILO

Chimney swifts return from the South about the middle of April, but where they have spent the winter is still a mystery, for the chimney swift is the one bird in eastern North America whose winter quarters have not yet been discovered. It is known that they go as far as Vera Cruz and it is probable that they winter somewhere in Central America or northern South America, but it is impossible to distinguish them from the native swifts as they soar high overhead and as yet none have been collected. They are common in all parts of the Eastern States until late September or October when they suddenly disappear. Just before this time and when they first appear in the spring, they sometimes occur in flocks of thousands and at dusk are seen circling about some tall chimney before settling to roost. For a time as they pitch headlong into the chimney and again as they rise in the morning, so numerous are they that for several minutes they look like smoke rising. At other times of the year they scatter, and it is doubtful if more than one pair ever nest in a single chimney although pairs from adjacent chimneys often fly in company and from the fact that they are often seen in trios, it has been suggested that they are polygamous. There is yet, however, nothing further to support this belief. At times

they sail with the wings held high over the back, but more often they fly with apparent alternate strokes of the wings and gain such momentum that few if any birds fly faster. Thus they circle through the hordes of midges and mosquitoes, probably with their mouths open, for they never seem to pursue any particular insect as do the swallows.

The three swifts found from the Rocky Mountains to the Pacific are the black swift, Vaus swift and the white-throated swift, the latter being considerably larger than the others and having the throat and breast white. A most interesting discovery has recently been made in connection with the black swift. It frequently remains dormant for days at a time in the crevices of the rocks when the weather is cold and wet, in a sort of hibernation. This is most unusual among birds which ordinarily require a constant supply of food to maintain life.

Nighthawks and Whip-poor-wills

To try to understand every impression that is made upon the senses is a sign of intelligence. The dog that howls at the moon because he does not understand it is more intelligent than the dog that takes the moon for granted We human beings know that every effect should have a cause, and, having sensed the effect, are quick to search the cause. So insistent are we if we do not discover it, that we invent one to our own satisfaction. Later on when our mistake has been rectified, it may cling to the world for generations as a rumor or a superstition. A good many generations have passed since a group of night-jars were disporting themselves one evening on a European pasture and some one inquired what they were doing. It must have been a disgruntled herdsman that offered the explanation that they were sucking the milk from the goats, but since goats never give as much milk as is desired, the explanation took hold. It was too dark to see the insects that the goats were disturbing but it was light enough to see that the birds were following the goats So, even today, the night-jars and their relatives, the nighthawks and whip-poor-wills, must retain the family appellation of "goat-suckers" and bear the ill-will of the non-observant world.

Nor is it from this superstition alone that these strange but useful birds have come into disrepute. The idea of a bird waiting until dark before it goes about its work is enough to prejudice most minds against it, and when besides this it is responsible for some of the weirdest sounds in all nature, even the most intelligent will lend a willing ear to fictions about it. When one is alone in the forest and a whip-poor-will breaks the silence with its strange liquid notes, it is easy to understand how the Indians came to believe that misfortune was imminent when its call was heard near his tepee. And when darkness has fallen on one of our

Photo by A. Dawes DuBois

THE WHIP-POOR-WILL AT HOME

The whip-poor-will builds no nest but lays its eggs on the leaves of the forest floor The upper picture, of the bird brooding on egg and young, offers a study of protective coloration The lower shows an egg and one of the downy young.

southwestern deserts and a chorus of poor-wills make the rocks resound, it is easy to imagine that there are evil spirits all about.

There are over one hundred species in the goatsucker family (*Caprimulgidæ*), found all over the world except in arctic and antarctic regions and a few of the eastern Pacific islands. About fifty are found in the New World, the majority in the tropics, so that only six reach North America. Four of these are rather well-known birds, the nighthawk, whip-poor-will, chuck-wills-widow and the poor-will. They are all small birds but their long wings and tails make them appear much larger than they really

are. The nighthawk, for example, whose body is smaller than that of the robin, appears, on the wing, about the size of a sparrow hawk. A few of the tropical woodland night-jars are considerably larger, about the size of short-eared owls, which, indeed, they somewhat resemble. Nor is it any wonder when we stop to consider the close relationship of the goatsuckers to the owls.

It is not only in color and nocturnal habits that the goatsuckers resemble the owls but structurally as well. So much so, in fact, that modern systematists remove the owls from the raptorial birds where they have rested for so long, and put them close to the goatsuckers. The principal differences between the two groups have arisen because of their differences in food habits. The owls are largely carnivorous and their bills and feet have been modified for catching mice. The goatsuckers, on the other hand, feed chiefly on flying insects and have little use for their bills and feet, so that these have degenerated while their mouths have developed to an extreme size. In all but the nighthawks, the corners of the mouths are provided with long bristles, making them most efficient scoop nets. The seven species of woodland night-jars (*Nyctibius*), however, have much heavier bills which are strongly hooked, and they have better developed toes. They differ also in assuming an erect, owl-like position when at rest and in having the eyes more nearly directed forward Indeed, in many respects, they seem intermediate between the rest of the goatsuckers and the owls. The nighthawks and whip-poor-wills, when at rest, always perch lengthwise of the branch or log because of the weakness of their feet. This, together with their eyes being on the sides of the head, destroys their similarity to the owls in spite of the fact that their plumage is just as soft, their colors similarly mottled and their eyes much larger than in ordinary birds.

In nesting habits, the goatsuckers are at the bottom of the scale. They build no nest whatever but lay their eggs on the bare ground without even a depression to keep them from rolling. The North American species normally lay two eggs, but the tropical species but one. The eggs are whitish or cream-colored, marked with darker gray and purplish, those of the nighthawk being quite inconspicuous on the gravel where they are usually laid, but those of other species being quite the reverse. The young are hatched blind and helpless but are soon covered with long grayish or brownish down not very different from that which covers young owls.

The most abundant and widespread of the goatsuckers is the nighthawk, which is found in summer in one or another of its sub-species from Florida to Alaska. In winter the nighthawk retires to South America, traveling in scattered flocks. Sometimes they just skim the ground or large bodies of water when, at a distance, they look remarkably like black terns. Again, they fly high overhead. In climbing the Andes of Colombia in October at an altitude of 12,000 feet, the writer once saw flocks of nighthawks flying several thousands of feet higher, crossing snow-capped ridges and making for the plains beyond. The birds that nest in Alaska have a long way to travel, for even should they stop in the Bahamas, it would mean 6000 miles each way, while if they continued to central Argentina, as do many, it would mean an annual pilgrimage covering at least 18,000 miles.

Nighthawks are usually birds of the pasture or prairie country and are seldom found in heavily wooded districts unless it be in clearings. They spend the day perched lengthwise on a rock or post or branch of a tree when they will frequently permit of a close approach. At dusk they begin hawking about after insects and consume great quantities of gnats, mosquitoes and other flying insects. Five hundred mosquitoes were found in the stomach of one nighthawk and eighteen hundred winged ants in another. Occasionally they pursue insects on bare ground and are sometimes seen at dusk along country roads, flitting from spot to spot capturing beetles and grasshoppers. Sixty grasshoppers were found in the stomach of one bird. They ordinarily feed only at dusk or at night but during the nesting season or on their migrations, they are sometimes seen darting about high overhead even on bright days.

In former years, the nighthawk was shot for sport in large numbers throughout the South where it was known as the "bull-bat". Its erratic flight made it a difficult mark for the gunners, and it was considered legitimate sport to go out at dusk and shoot them as they darted back and forth over the pastures after insects. Sometimes they were used as food. For a time they became extremely scarce and in some localities were threatened with extinction, but now that their value has come to be realized, and they are rigidly protected by both state and federal laws, shooting them has gone out of vogue, and they are increasing in number.

In recent years, the nighthawks have been attracted to large cities where the flat-topped buildings with their gravel roofs are not very different from the stony fields where the birds ordinarily nest. They have little competition from other birds for the host of flying insects that are attracted by the lights, and they are steadily increasing. They are often seen perched on chimneys or gables during the day and darting overhead at dusk uttering their sharp call of "peerd-peerd". During the breeding season they can often be seen to dive toward the earth from a considerable height, catching themselves with an upward turn just before they strike the house tops, the rush of the air through their wings causing a roaring sound like that produced by blowing over the bunghole of a barrel.

The nighthawk and the whip-poor-will are quite similar in appearance, both being beautifully mottled gray and brown, somewhat lighter below with conspicuous white patches on the throats and white in the tail. The nighthawks are easily distinguished by a white bar across the wing which is very conspicuous during flight. The two birds, however, are not ordinarily found in the same kind of places and their habits are quite different.

The whip-poor-will is a bird of the woodlands, spending the day on the ground under the trees and coming out into clearings or along the forest borders at night to feed. At such times it sometimes ventures close to door-yards and startles the unsuspecting householders by its loud liquid notes — "whip - poor - will — whip - poor - will — whip-poor-will." They are given with an accent that does not tend to make one sorry for poor Will but rather to feel that he quite deserves all that is coming to him.

The whip-poor-wills feed upon larger insects than the nighthawks, being particularly fond of the large night-flying moths, the larvæ of which are very destructive to the foliage of trees.

Whip-poor-wills are found in summer from Florida to Nova Scotia as far west as the plains. They leave with the nighthawks for the South the last of September or the first of October, but they do not go as far, for they stop in Central America and the West Indies.

Photo by A. Dawes DuBois

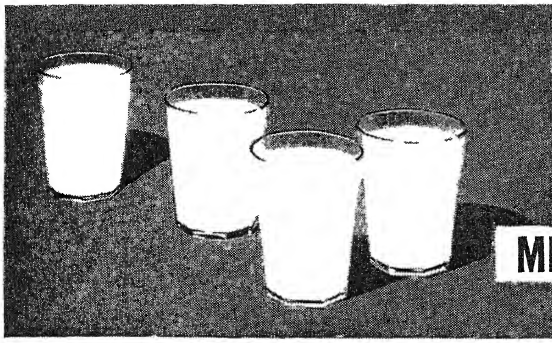
ANOTHER CASE OF CAMOUFLAGE

The Western nighthawk on its eggs.

In the Gulf States and occasionally as far north as Maryland and Ohio, occurs the chuck-wills-widow which is a larger edition of the whip-poor-will. In habits it is not very different except that it is occasionally known to pursue and swallow such small birds as warblers and sparrows, and hummingbirds have been taken from their stomachs.

The whole family of goatsuckers is without exception one of the most beneficial that we have. An occasional small bird swallowed by the chuck-wills-widow is the only exception to a diet that is almost exclusively insectivorous. They capture the night-flying insects which have few other bird enemies and some of which are the most destructive that we have. Their weird calls and nocturnal habits will undoubtedly continue to prejudice unthinking people against them and we should, therefore, do everything in our power to disseminate the truth and cultivate a love and respect for them.

OUR DAILY FOOD

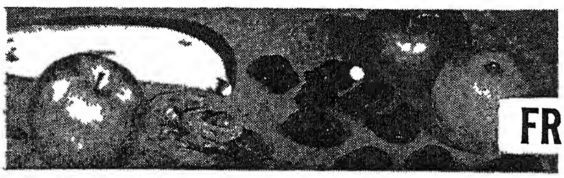


MILK

2 OR MORE GLASSES DAILY FOR ADULTS; 3 TO 4 OR MORE GLASSES DAILY FOR CHILDREN . . . to drink, combined with other foods, in ice cream and cheese

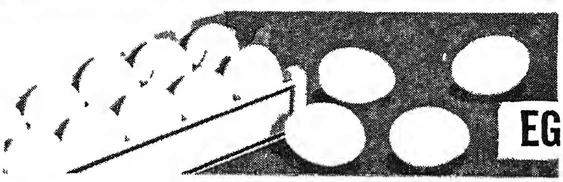
VEGETABLES

2 OR MORE SERVINGS DAILY BESIDES POTATO . . . 1 green or yellow; greens often



FRUITS

2 OR MORE SERVINGS DAILY . . . at least 1 raw; citrus fruit or tomato often

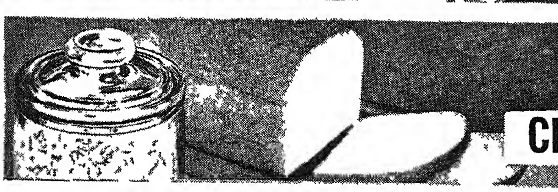


EGGS

3 TO 5 A WEEK; 1 DAILY PREFERRED

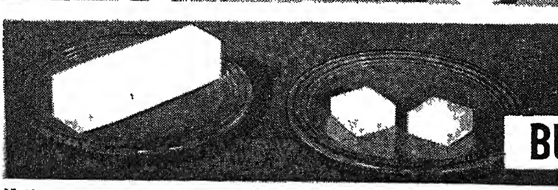
MEAT, CHEESE, FISH, FOWL

1 OR MORE SERVINGS DAILY . . . dried beans, peas, peanuts occasionally



CEREAL AND BREAD

2 OR MORE SERVINGS DAILY . . . whole-grain value or enriched



BUTTER

2 OR MORE TABLESPOONS DAILY

National Dairy Council

The above guide to good eating represents the body's minimum requirements. Other foods may be added to satisfy the appetite and to answer the growth and activity needs of the individual.

SOME PROBLEMS OF DIET

What We Should Eat and When and How We Should Eat It

THE KIND OF FOODS NEEDED BY THE HUMAN BODY

THE pioneer settlers of this country had at least one great advantage over us. they were not embarrassed by the question, "What shall I eat?" They ate everything there was to eat, and because their bodies were very active, they probably ate with relish foods which we would scarcely care for. At the present time there are so many articles of food in the market, so many kinds of meat on the bill of fare, so many package and ready-to-serve foods in the shops, so many vegetables and fruits coming in fresh all the year round that the effect is bewildering. The selection of proper nourishment cannot be left to chance nor to the caprice of appetite. The matter really merits a little serious thought; for on the one hand it is literally possible to starve oneself (of important food constituents) in the midst of plenty, and on the other, it is not only possible but probable that, unless we give special attention to the matter, all of us will suffer in some way from eating too much.

In order to give an intelligent answer to the question *what* to eat one must give careful consideration to several underlying questions: (1) what is food; (2) what purpose is served by each kind; (3) where the essential constituents of a diet may be obtained; and (4) which combinations of these elements best fulfill the requirements.

The human body is a self-building, self-regulating, self-repairing engine. The gasoline engine gets its power from its fuel; the fuel is burned and its potential energy is transformed into mechanical power and heat. The body does the same. Food is oxidized and its latent energy is transformed into functional power and heat. But no engine builds itself and keeps up repairs out of materials supplied for fuel as the body does; few engines can utilize so large a percentage of the fuel energy for useful forms of work; no engine can use its own substance for fuel when the supply runs short, or store up an excess of fuel in a form easily convertible into work and heat, for a colder day. All these things that marvel of mechanisms, the human body, can do.

Food is any substance which the body can make use of: (1) either to furnish material for its growth and repair; (2) to supply its energies; or (3) to regulate and harmonize the working of its parts.

The air is not usually thought of as food and yet one of its elements, oxygen, is the most important substance which the environment has to offer. A person can live without food thirty days, without water three days, without oxygen not more than three minutes. What the draft is to the furnace, the oxygen we breathe is to the human cells. Some cells of the body, as the muscle cells, utilize the energy which comes from oxidation to do external work, *i.e.* work in the sense in which an automobile does work. In so doing they produce a large amount of heat which the body uses to keep itself warm. Other cells, as the liver cells, produce a large amount of heat by oxidation without doing any external work. The work they do may be called by contrast "internal" work. It is work in the chemical rather than in the physical sense. This work is even more important than the physical work; for a thing may be alive without doing any external work, but nothing can remain alive for so long as half an hour without doing chemical work.

The heat resulting from these chemical changes is likewise used to keep the body at a certain definite temperature. In the next chapter we shall see how its production is very nicely adjusted to the needs by a regulating mechanism.

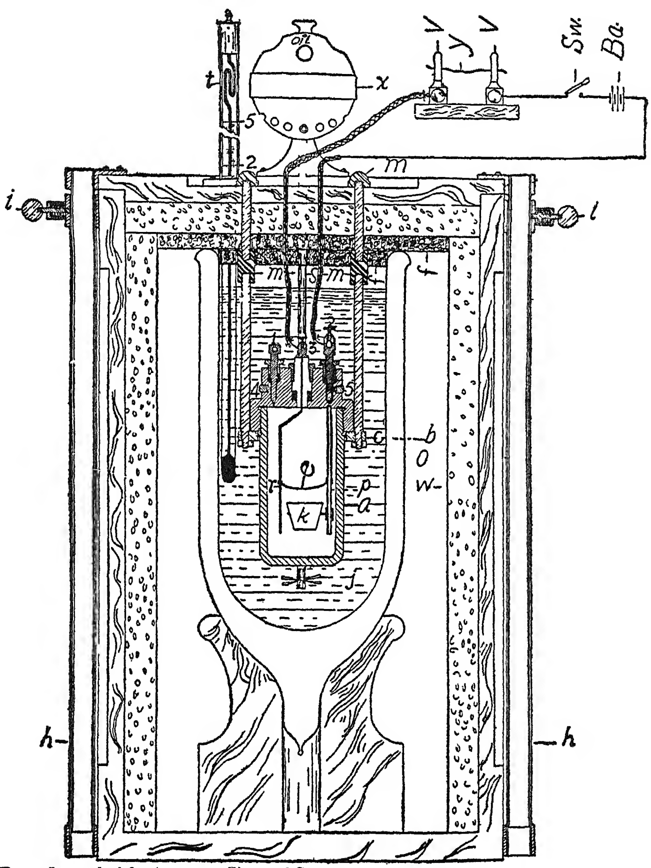
If we pursue this need for oxygen a little farther we learn that there is something beyond the need for physical energy (movement) and chemical energy (heat) — that merely to keep alive requires oxygen. For there are organisms which do not keep themselves warmer (plants, generally speaking, keep themselves colder) than the atmosphere or the water in which they live; and many, many organisms do not move of their own effort. But they nevertheless use oxygen — cannot live indeed without it. So it is with some cells of our bodies. They do no external work, they produce no heat and yet they require oxygen to keep alive. We may think of this need as the least dispensable of all, because the oxygen probably maintains the very structure which alone can manifest life.

The fuel foods

Let us now turn from the draft to the fuel itself. If we trace the foods which yield us most energy to their sources and inquire where that energy came from, we soon come back to the green plant and find that the energy of all living things is derived from the sun. Plant life has the advantage over animal life that it can make direct use of the sun's energy. Green plants contain a substance named "chlorophyll" which is, probably, the most potent substance in the world. Some poet should write an ode to chlorophyll, the mighty magician with the beautiful name, who transforms the giant energies of the solar furnace with less than a touch into food for the teeming billions not only of the human race, but of all animals of land, sea and air. This marvelous substance in the leaf takes the energy of the sun's rays and with it enables the plant to act on the carbon dioxide breathed in from the air. Scientists think that this is converted into carbon monoxide and subsequently combined with water from the roots into a highly poisonous substance found in minute traces in the leaves. Already this simple compound contains energy which can be set free by oxidation; but if we were to eat it as a food it would kill us, for it is none other than the deadly poison formaldehyde, which we use to kill germs. The magician is not through with it, however, for no sooner is it formed than it is at once tied up with five similar molecules to form sugar, and the sugar, carried to the seed or the root or the stem of the plant in the sap, is quickly transformed again into starch. As starch or as sugar we can make use of the material; for these are at once the cheapest forms of energy which we can buy and the most readily prepared for our cells. We can easily understand why this form of energy is not costly to man; for nearly all the labor which goes into the product is performed by the sun under the sorcery of chlorophyll. All man needs to do is to place the seed in the prepared ground, keep the weeds away and keep the soil cultivated, and the sun does the rest. A thoughtless farmer may be under the impression that he does the work. To get a fair notion of how much work he does, he need only compare the food energy which he consumes while tending the crop with the food energy which the crop can yield when it is harvested. One man's bodily energy is thus multiplied into the energy of a thousand. The agent is our magician chlorophyll, and the power comes straight from the sun.

The plant makes the starch, of course, for its own use or the use of its offspring, the next generation. Starch stored in seeds like rice, corn, wheat, oats, beans, etc., is placed there to be of use when the young plant germinates. Starch placed in the apple, the banana, the potato and the carrot is for a similar purpose although it is not in the seed. Fortunately plants produce many seeds, for most of these seeds are eaten by man, especially of the grain and cereal crops. Some plants, notably oranges and grapes, are carefully cultivated, however, because they produce fruits without seeds and make for more pleasant eating than the conventional kinds.

Some plants go still farther in the manufacture of energy-yielding foods for us. A good example is the olive tree. Not content with storing starch around the seed, it converts much of the starch to a very nutritious oil. Many nut-bearing plants do the same: the "nut" we are most fond of — the peanut (which is, strictly speaking, not a nut at all, but an underground bean) — is good for use, in moderate quantity, partly because of the oil it contains. These oils (olive oil, peanut oil, cocoanut oil, cotton-seed oil, etc.) are spoken of as "rich" foods because the energy in them is very concentrated. They cost us more in pure form than starch because more human energy must be expended to make them available to us. Animal fats have a similar energy value to that of the vegetable oils.



From *Journal of the American Chemical Society*

CALORIMETER (RICHE) TESTING HOW MUCH ENERGY A FOOD CONTAINS

The food is placed in *k* and is ignited by sending a known amount of current through *e* *a*, Krocker bomb; *b*, vacuum cup, *c*, split ring; *e*, platinum wire; *f*, felt; *h*, hole in inner tube; *i*, spring stops; *j*, stirrer; *k*, capsule; *m*, fiber; *o*, cork; *p*, platinum tube; *r*, platinum rod; *s*, stirrer rod; *t*, thermometer; *v*, fuse wire posts; *w*, wooden box; *x*, motor; *y*, fuse wire; *Sw*, switch; *Ba*, storage batteries; 1, valve screw; 2, valve screw; 3, insulated post; 4, inlet screw; 5, inlet screw.

There is a very pretty way of telling exactly how much energy a food contains. Whatever we do with the energy we get from a food, aside from performing external work, whether we use it in grinding and digesting food, in driving the blood around, or in thinking, it finally takes the form of heat; even the work we do on external objects can be measured as heat. Hence the best measure of the energy a food can yield — the measure which will cover every last trace of energy — is one expressed as heat. The starches and oils, — the energy-yielding foods, — when burned in the body, give up all of their heat, and this is exactly the amount they will yield when burned outside of the body, provided the combustion is complete in both cases. Ordinarily we need take no special precautions to make it complete in our bodies, for our cells have that wonderful power which every automobile manufacturer would be glad to imitate if he could, of making the fuel burn without kindling or sparking. Outside the body, however, in order to make a food burn completely we must surround it with pure oxygen and then fire it with an electric spark. The heat given off is caught in water and we tell how much heat there is by noting the rise in temperature of the water. The amount of heat required to raise the temperature of a kilogram of water one degree centigrade is called a large calorie, or great calorie or kilogram calorie. This is the unit that is usually used in measuring the heat-producing or energy-producing value of food.

The layman is inclined to be a little frightened by this term. We must remember that it means only "energy unit". Doubtless there have been good engineers who knew how to judge coal fairly well without burning it in a calorimeter, but no modern power engineer would neglect such an accurate means of finding out what he needs to know, namely, how much power he can get out of his coal. So also if you wish to know how much power you can get out of any food, you must know how many calories it will yield to your body. We make no claim that this is all you need to know about food. That we shall see as we proceed.

All the foods available in our wonderfully varied markets in this country have been tested many times and the heat values have been tabulated, so that any housewife, or any other person interested, can find out whether the money will go farthest in buying energy if spent for potatoes, or for rice, and so on

It makes little difference to the body which of the two kinds of food we have thus far been talking about you give to it; only this we must remember: a given weight (pound, ounce or gram) of oil or fat will, if pure, give us more than twice as much energy as the same weight in either starch or sugar of any kind. A pound of starch will yield about 1850 calories; a pound of pure olive oil 4200 calories. A man can eat food consisting mainly of starches and sugars and very little oil and get his energy from them, or he can eat foods which produce oil or fat abundantly and get his energy from them, or he can mix the two and get along. There is doubtless a *best* proportion of these two classes, fats and carbohydrates, but it is certainly not the same for all. Persons doing heavy muscular work find that the muscular effort can be made with greater ease and comfort to the worker if there is plenty of carbohydrate in the diet, while for persons of sedentary habits too much carbohydrate easily produces fermentation in the stomach and may lead to overstrain on some organ. The fats should never be entirely excluded; for besides giving energy in its most concentrated form and serving therefore to keep down the bulk of food which one must put into the stomach, they serve also as a solvent of certain important constituents which will be mentioned later

Carbohydrates are most readily prepared for absorption and are most readily burned of all our foods; an excess can, as a rule, be converted to fat and stored against a time of greater need for energy

In general a person would be on safe ground if he were to take one-fourth of his energy in the form of fat and three-fourths in the form of carbohydrate or carbohydrate-yielding substances.

Not less than three-fourths of all the food we eat goes for the purpose of supplying energy and nothing else. For the laboring man the proportion is greater.

The building and repair foods

Now we come to another kind of foods, namely, those which are necessary for building and repair. The most important is the great class known as "proteins". They constitute the very sinew of life. The most familiar members of this class are of animal origin: lean meat, fish, milk, eggs. Vegetable proteins are furnished by peas, beans, lentils, nuts, etc., yielding highest percentages, the cereals yielding moderate amounts, and the succulent vegetables and fruits coming last.

All the foods which supply energy contain carbon, hydrogen and oxygen; but protein alone supplies nitrogen, without which neither growth nor repair can take place.

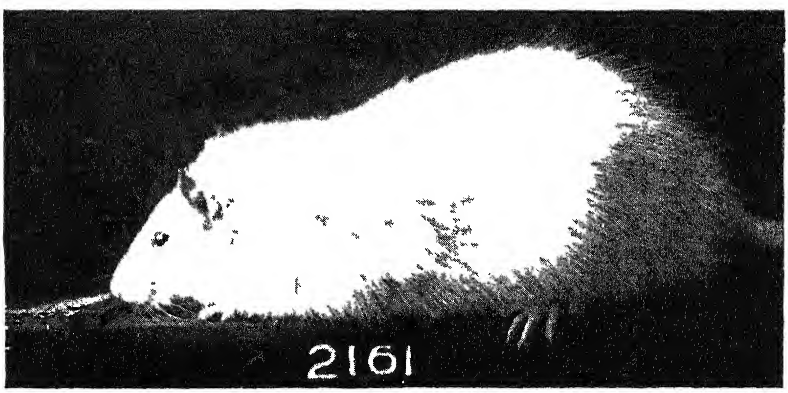
Proteins separated in pure form have the general appearance and properties of white of egg. They are built up of varying combinations of eighteen simpler substances containing nitrogen, called "amino acids". A certain group of them, as the proteins of milk, meat, egg, use all these amino acids and are called "complete" proteins. In certain others, such as gelatin and some of those produced by plants, certain important amino acids are wanting; they are therefore called "incomplete" proteins.

Professor Graham Lusk has suggested that the former group should be desig-

nated "Proteins of grade A"; the latter "Proteins of grade D". Grades B and C would constitute mixtures of complete and incomplete proteins in different proportions such as occur, for example, in wheat (B) and corn (C) respectively. Such a designation on the label of package foods, if required by law, would enable the purchaser to know what protein value he was buying. Only proteins of grade A can replace body protein part for part. Proteins of grade D have almost no value in this respect and proteins of grades B and C are adequate only because an incomplete protein is supplemented by a complete one in the same plant. The incomplete proteins will not support growth. This has been demonstrated conclusively for certain animals and is undoubtedly true for children.

This division of our subject is so important from the standpoint of those who are responsible for the choice of foods for the family that we must look into it a little farther. After the discovery by Emil Fischer that proteins are made up of nothing but amino acids, Hopkins in England instituted the first experiments designed to ascertain which of the amino acids are essential. Feeding young rats with zein, one of the proteins found in Indian corn, as the only nitrogenous constituent of the food, Hopkins found that the animals would survive for only a short period. The reason, as it soon developed, was that this protein lacks two of the eighteen amino acids. When one of these, which has the rather formidable name of "tryptophane", was added the rats survived for a much longer time, but still did not grow satisfactorily. The diet became only what one would call a "maintenance" diet. In this country it has since been shown by Osborne and Mendel that when the other amino acid lacking from zein, "lysine" by name, was added in addition to the tryptophane, growth became normal.

The comparable photographs of Rat 2161 from Mendel and Osborne, *Journal of Biological Chemistry,* show the animal (below) at the age of 246 days and 71 5 gm body weight after a prolonged suppression of growth on a diet in which the essential nitrogenous component consisted of the protein zein with the addition of tryptophane and lysine in small amounts



Growth was resumed at the age of 248 days on a diet in which zein and the amino acids were replaced by casein The upper photograph shows the same rat at the age of 459 days with a body weight of 295 gm The photographs were made under exactly comparable conditions with respect to focal distance, apparatus, etc.

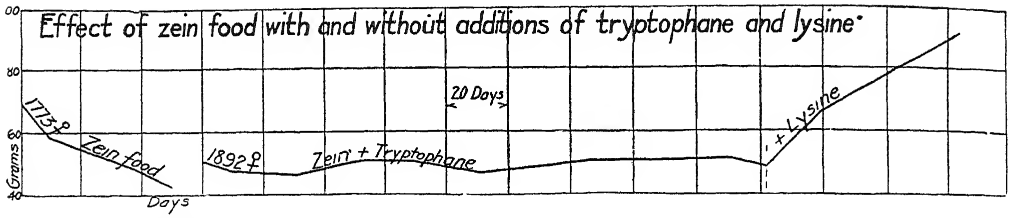


Chart showing *nutritive decline* on zein food, *maintenance* after addition of tryptophane, *growth* after addition of both tryptophane and lysine. Rat 1892 was maintained during one-half year without significant change in body weight on the zein + tryptophane food. Despite this inadequate diet the capacity to grow was not lost at the end of this prolonged period, and the animal ultimately grew to full adult size on a mixed diet.

These were the beginnings of much important work looking to the establishment of the correct nutritional value for the different proteins. Osborne and Mendel are now able to state definitely that adequate growth can be fostered with albumin of milk, albumin of eggs (also the characteristic protein of the yolk), with glutenin of wheat, glutenin of corn and so forth. All of these therefore may be called "adequate" proteins. It is interesting to note that many grains which produce an incomplete protein, such as wheat with its gliadin, corn with its zein, make up for the deficiency by producing along with it a complete protein. The same is true of milk; for casein, which makes up the bulkier protein of cow's milk, is inadequate alone to support growth, whereas the albumin of milk — the protein which forms the "skin" when milk is boiled — is quite adequate. Mother's milk, we may note in passing, is much richer in this protein than is cow's milk. It turns out that foods designed by nature as a source of building material in the young, eggs and milk, are rich in the two essential amino acids tryptophane and lysine.

The processes of digestion and assimilation separate the individual units of protein and rearrange them into body protein in a manner similar to that of tearing down an old house and using the stones to build a new one. All of the building stones must be cleaned and many must be reshaped to be fit for use in the new structure. Digestion may be said to be the reduction of food substances to their simplest elements; the digestion of proteins is the process of reducing them again to their amino acids. In the words of Lusk, "These amino acids may be compared to the letters of the alphabet. When they are arranged together they can make many different proteins just as there are many words in the dictionary. For example, suppose the word 'albumin' were broken up by digestion into the letters, *a*, *b*, *i*, *l*, *m*, *n*, *u*; these letters absorbed could be reconstructed into albumin again. The same may be said to be true for the word 'globulin.' Now if both albumin and globulin were to be formed from a common word, one would have to eat a hypothetical substance called 'amglobulin', convertible into globulin if the letters *a*, *m* are abandoned to their fate, or into albumin on neglecting the letters *o* and *g*. Carrying the analogy still further it is evident that if the letter *b* were not in the word 'amglobulin', neither albumin nor globulin could possibly be produced. Incomplete proteins, *e.g.* many plant proteins and gelatin, lack some important amino acid, — just as the hypothetical word might lack *b*. They alone cannot be reconstructed into body protein Some other food must be added to supply these lacking units."

Fortunately for our general health most protein foods contain so good an assortment of amino acids that an adult on ordinary mixed diet need have no concern as to the kind of protein he is eating. But in choosing a diet for growing children it becomes a matter of importance.

Various plant proteins are eaten by cattle and sheep, one kind supplying the units lacking in another, and when the animals have eliminated the units not necessary for the structure of their own body cells, the animal protein has acquired a higher food value than that possessed by any single vegetable protein.

"The body of an average man weighing 150 pounds contains 30 of protein, or 20 per cent of the live weight. If a man starves he will lose five parts per thousand of his protein store daily. If he be given fat and carbohydrate in large quantity, the daily loss of protein may be reduced to 2.5 parts per thousand. This loss of body protein represents the irreducible minimum of wear and tear on the constituent parts of the machinery of the cells." This minimal loss of protein cannot be prevented by giving gelatin, as has been demonstrated by experiment (nor indeed by any other incomplete protein) with the fats and carbohydrates. But if protein in the form of beef, in quantity equal to the irreducible minimum of wear and tear, be added to the diet of fat, carbohydrate and gelatin, the waste of body protein stops at once. Wheat proteins were found to be far less efficient than beef in protecting the body from protein loss.

Experiments by Thomas have demonstrated the relative biological value of different proteins. The following are the least daily amounts which will protect the body from protein loss: meat protein, 30 grams; milk protein, 31 grams; rice protein, 34 grams; potato protein, 38 grams; bean protein, 54 grams; bread protein, 76 grams; Indian corn protein, 102 grams. When we recall that only 7.5 per cent of bread is protein and only 4 per cent of corn meal, it will be seen that to get a sufficient quantity of protein from these latter would require a very inconvenient amount to be eaten in one day.

"Protein is usually taken in excess of that bare requirement which is measured by the quantity necessary to repair the tissue. This excess is oxidized and used for fuel just as are fat and carbohydrates. Protein has one property out of all proportion to that possessed by other foodstuffs; it very largely increases the production of heat in the body. Persons maintained on a low protein diet may suffer intensely from the cold. One may cause the heat production of a dog to double by giving it three pounds of meat. This heat-increasing property of protein is called its "specific dynamic action."

It is well to emphasize that while protein is absolutely necessary to maintain tissue in repair, to promote growth, and to stimulate heat production, it is not economical as fuel. Nearly all the food we eat is for fuel, and the cheapest fuel is carbohydrate, and after it fat In starvation the carbohydrate reserve is burned first, fat second, and the protein as a last resort, showing that the body knows how to protect itself against the loss of this most precious material and takes steps accordingly.

Salt-like foods

Besides nitrogen, proteins form the main source of two other important elements, namely, sulphur and phosphorus. Sulphur is needed especially for such structures as hair and nails; in combination with calcium, phosphorus is especially needed for the bones. Both enter also into the composition of living protoplasm throughout the body.

Both these elements are supplied to the body to some extent also in the form of salts. Both are present in this form in meat, and the acid radical here being in excess of the basic radical the ash of meat is acid in reaction. It is important to bear this in mind; for when digestion takes place and the protein of the meat is absorbed, this acid ash is set free and is absorbed along with the protein. An excess of meat therefore always produces a strongly acid urine for the reason that these acids must be removed as rapidly as they are formed. There is danger, however, from excessive meat eating that the acid will not be removed fast enough.

Most vegetables and fruits, even those which taste acid, contain a basic ash and if plenty of vegetables like potatoes, carrots, beets, turnips, cabbage, etc., are eaten with the meat, the surplus of acid is neutralized. Under these conditions uric acid will be readily dissolved and removed from the system and any tendency to gout will be counteracted. Milk yields an almost neutral ash. Most cereals yield an acid ash, but the acidity is much less than that of meat. The ash of rice is more acid than that of potatoes.

Iron is another essential mineral element. A person lacking the requisite number of red blood corpuscles or the required percentage of iron therein is said to be "anemic", and this lack must quickly be supplied. Very small quantities are needed, but they are absolutely essential. It is found in many foods, especially in egg yolk, spinach, string beans, cabbage and lean beef.

Calcium is necessary for the formation of strong bones and teeth. Cow's milk is the food richest in calcium, being 24 times as valuable for that element as white bread and meat. It may be obtained from wheat and other grains if the entire outer coat is used, as in whole-wheat bread, and from many vegetables, as cauliflower, celery, spinach, cabbage and carrots.

The nice balance between the functions of the various glands, between the muscles and the nerves, between the composition of the blood and the action of the heart is all maintained by means of the presence of chlorine, calcium, magnesium, sodium and potassium, held in solution in the proper proportion. These elements are grouped together and called "salts" or "mineral matter" or "ash constituents", because they are left behind as ashes when the food is burned. The relative amounts of these different elements in the adult body is shown in the following table.

AVERAGE ELEMENTARY COMPOSITION OF THE HUMAN BODY

Oxygen, about	65.0	per cent
Carbon, about	18.0	per cent
Hydrogen, about	10.0	per cent
Nitrogen	3.0	per cent
Calcium, about	2.0	per cent
Phosphorus, about	1.0	per cent
Potassium, about	0.35	per cent
Sulphur, about	0.25	per cent
Sodium, about	0.15	per cent
Chlorine	0.15	per cent
Magnesium, about	0.05	per cent
Iron, about	0.004	per cent
Iodine, Fluorine, Silicon	very minute quantities	

Vitamins

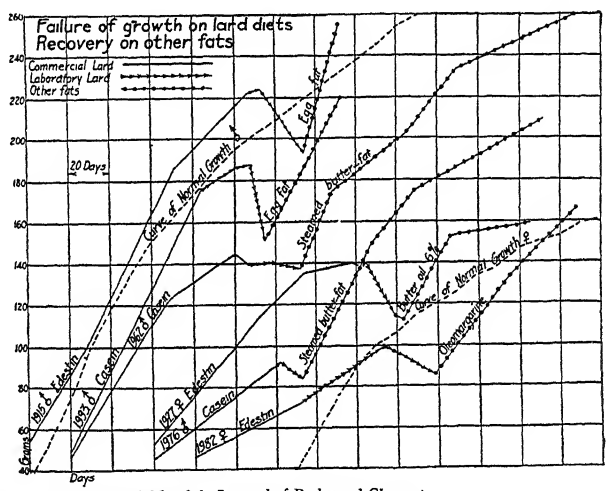
In addition to all the foods discussed there are minute quantities of other substances whose chemical nature has been determined, and which have a profound influence upon nutrition. Some physiologists call them "vitamins", some "accessory substances" or "food hormones". It has been shown by experiment that a strictly pure diet of carbohydrates, fat and protein, with proper proportion of ash, will not cause animals to grow unless some unrefined natural food is added. People living entirely on polished rice as a source of vegetable matter develop a disease known as "beri-beri", which can be cured by adding the brown husk or coating of the rice grain lost in the polishing process. People who live too largely on refined corn meal and fat meat are often attacked by a kindred nutritional disease called "pellagra", which may be cured by adding meat, milk or eggs to the diet. Sailors on a long voyage often develop scurvy, but usually recover when allowed to eat freely of fresh vegetables. Babies fed on boiled milk or prepared food must occasionally have orange juice or fresh milk for a similar reason.

Under ordinary conditions there is little danger of any of these diseases. It is interesting to know that even savage people intuitively supply these accessory substances in some form. Captain Cook, the explorer, avoided scurvy on his second voyage, although it lasted 1000 days. He says: "We came to few places where either the art of man or nature did not afford some sort of refreshment, either of the animal or vegetable kind. It was my first care to procure what could be met with and oblige our people to make use thereof, both by my example and authority; but the benefits became so obvious that I had little occasion to employ the one or the other."

It is therefore important not only to estimate the value of the diet in calories and its content of carbohydrate, fat and protein, but to see that this small quantity of "accessory factors" or "vitamins" is present.

McCollum found, in studying the effect of foods on the growth of young animals, that there were several essential "accessory substances". One of these, which he called *A*, has since been resolved, and is contained dissolved in certain fats and oils, as the fat of milk (butter) and the oil of hemp seed. Another, which he called *B*, is soluble in water and can be extracted from various animal and plant substances; for example, liver and yeast. In the absence of either of these accessories growth does not take place satisfactorily. These vitamins and others since discovered are discussed in greater detail in another chapter. Dietetics has become a science.

Carrying out the figure of speech with which we started, if we compare the energy-yielding foods to the fuel of the automobile, the protein and salts to the "parts" which must be constantly supplied, the vitamins may be compared to the lubricating oil which makes all the parts of the machinery run smoothly.



From Osborne and Mendel, *Journal of Biological Chemistry*

Cessation of growth and nutritive failure on diets containing "laboratory lard" as the sole fat Restoration of growth by replacing part of the lard with egg-fat, butter-fat, "butter oil" or commercial oleomargarine.

The food mixtures consisted of. protein, 18 per cent; protein-free milk, 28 per cent; starch, 24–29 per cent; lard, 7–28 per cent; other fats, 0.18 per cent.

Food fallacies

There is a popular impression that one should eat red meat for muscle development and fish for brain food. The public is asked to believe, for example, that a certain widely advertised breakfast cereal promotes clear thinking. The statement that fish is a particularly good brain food is based on the unquestioned fact that fish and brain substance are rich in phosphorus. What the advertiser of fish or cereal food is perfectly willing you should infer is, that by eating such food you improve the quality and quantity of your mental machinery.

The same reasoning is applied to potash. "The brain contains potash; my food is rich in potash; therefore you should eat it."

The fallacy of such reasoning is twofold. First, there is no satisfactory evidence that the composition of the brain can be changed by eating a particular brand of food, providing the blood is of normal composition; and second, good brains, the basis of astute minds, have been grown and nourished on a thousand different dietaries.

Everybody knows that a person cannot acquire strong muscles by eating the muscles of animals, namely, meat. If this were a correct principle of nutrition, then in order to have strong brains and therefore powerful minds, we should eat the brains of animals (headcheese). Exercise is the key to strength as regards muscle, and if exercise is persisted in, strong muscles can be developed on any number of different dietaries. Just so with the brain, "strength comes from spending what you have", and there are numberless articles of food which can supply the requisite building and restorative substances. What the brain takes from the blood does not depend on the particular food we eat. *What any organ takes from the blood depends on the need of that organ.*

Civilization seems to advance most rapidly with a varied dietary. This is perfectly rational, too, for the body's needs, while never very large for any one substance, are extremely numerous. It would require a university education simply to name intelligently the different substances found in the human body. In this respect the body is somewhat like a factory force

Each constituent has a special function. One stands a much better chance of finding an efficient occupant for each place if there are a large number of applicants. Some day we shall know the qualifications of each constituent and shall be able to choose more intelligently.

This brings us to the subject of vegetarianism. Many people have convinced themselves that clear thinking and right living are only attainable by subsistence upon products of the vegetable kingdom, although many who call themselves "vegetarians" partake of milk, butter and eggs. From the scientific — that is, common sense — standpoint, there is only one objection which can be fairly urged against the inclusion of meats in the dietary, and that is, they are too easily digested. It sounds paradoxical to speak of a food as being too readily digested, but in the case of meats that is literally true, even when they are not thoroughly cooked. When stomach digestion is good, meats are very rapidly resolved into products which can enter the blood. If these products reach the blood in larger quantities than needed for repair, they are taken to the liver and are split up, a portion being worked over into urea for excretion by the kidneys, and another portion stored or burned. If the quantity eaten is large, the work of removing the surplus may be considerable, and in time may overtax the organs concerned. The rational thing to do, therefore, is to eat meats very moderately. With this precaution enforced there is no good reason why so valuable an article of diet should be stricken from the list of advisable foods. On the contrary there is good reason for believing that a certain stimulating effect is obtained from meats which is obtainable from no other source.

Because meats are too readily digested, and therefore too completely absorbed into the blood, leaving too little residue to be voided, they tend to produce constipation. The same may be said of white bread and milk. When any of these are eaten there should always be some coarse food, which is not so readily digested, taken with them. This "roughage" aids the digestion and wards off constipation.

Digestibility

In general it may be said that most foods are more completely digested than is commonly supposed. Some, however, contain a considerable proportion of insoluble material. For example, the outer hull of the wheat grain contains woody substance which resists the action of the digestive ferments in the human alimentary canal, though a large part of it can be assimilated by cows and sheep. It is not without value as ballast in man's dietary, however, for too finely milled grains are largely responsible for a tendency to constipation.

In the total food of an ordinary diet, according to Atwater, about 92 per cent of the protein, 95 of the fat, and 97 of the carbohydrates is retained in the body. In the average proportions in which different animal and vegetable foods are combined in the diet, about 97 per cent of the protein, 95 of the fat and 98 of the carbohydrates of animal food is digested, while only 84 per cent of the protein, 90 of the fat, and 97 of the carbohydrates of vegetable foods is digested. Animal foods therefore have a greater digestibility than vegetable, especially as regards the protein they contain. Of two cereals containing about the same amount of dry matter, but with different proportions of protein and carbohydrates, the one with the larger proportion of the less digestible protein and the smaller proportion of the more digestible carbohydrates will be, on the whole, less completely digested.

Kind of Food	Digestibility per cent		
	Protein	*Fat*	*Carbohydrate*
Meat and fish	97	95	98
Eggs	97	95	98
Dairy products	97	95	98
Animal food of mixed diet	97	95	98
Cereals	85	90	98
Legumes (dried)	78	90	97
Sugars			98
Starches			98
Vegetables	83	90	95
Fruits	85	90	90
Vegetable food of mixed diet	84	90	97
Total food of mixed diet	92	95	97

DIETARY YARDSTICK

Calories

Man weighing 154 pounds:
- Moderately active—3,000.
- Very active—4,500.
- Sedentary—2,500.

Woman weighing 123 pounds:
- Moderately active—2,500.
- Very active—3,000.
- Sedentary—2,100.

Children up to twelve years:
- Under one year—100 calories per kilogram of weight.
- 1–3 years—1,200.
- 4–6 years—1,600.
- 7–9 years—2,000.
- 10–12 years—2,500.

Children over twelve years:
- Girls, 13–15 years—2,800.
- 16–20 years—2,400.
- Boys, 13–15 years—3,200.
- 16–20 years—3,800.

Pregnancy (later half, for 123-pound woman)—2,500.
Lactation period—3,000.

Proteins

Man—70 grams.
Woman—60 grams.
Pregnancy—85 grams.
Lactation period—100 grams.
Children up to 12 years:
- Under 1 year—3 to 4 grams per kilogram of weight.
- 1–3 years—40 grams.
- 4–6 years—50 grams.
- 7–9 years—60 grams.
- 10–12 years—70 grams.

Children over 12 years:
- Girls, 13–15 years—80 grams.
- 16–20 years—75 grams.
- Boys, 13–15 years—85 grams.
- 16–20 years—100 grams.

Calcium

Man—0.8 gram.
Woman—0.8 gram.
Pregnancy—1.5 grams.
Lactation—2.0 grams.
Children, up to 9 years—1.0 gram.
- 10–12 years—1.2 grams.

Girls, 13–15 years—1.3 grams.
- 16–20 years—1.0 gram.

Boys, 13–20 years—1.4 grams.

Iron (Milligrams)

Man and woman—12.
Pregnancy—15.
Children, under 1 year—6.
- 1–3 years—7.
- 4–6 years—8.
- 7–9 years—10.
- 10–12 years—12.

Boys and girls, 15–20 years—15.

Vitamin A
(International Units)

Man or woman—5,000.
Pregnancy—6,000.
Lactation—8,000.
Children under 1 year—1,500.
- 1–3 years—2,000.
- 4–6 years—2,500.
- 7–9 years—3,500.
- 10–12 years—4,500.

Girls. 13–20 years—5,000.
Boys, 13–15 years—5,000.
- 16–20 years—6,000.

Vitamin B_1 (Thiamine)
(Milligrams)

Man weighing 154 pounds:
- Moderately active—1.8.
- Very active—2.3.
- Sedentary—1.5.

Woman weighing 123 pounds:
- Moderately active—1.5.
- Very active—1.8.
- Sedentary—1.2.

Pregnancy (later half)—1.8.
Lactation—2.3.
Children under 1 year—0.4.
- 1–3 years—0.6.
- 4–6 years—0.8.
- 7–9 years—1.0.
- 10–12 years—1.2.

Girls, 13–15 years—1.4.
- 16–20 years—1.2.

Boys, 13–15 years—1.6.
- 16–20 years—2.0.

Vitamin B_2 (Riboflavin)
(Milligrams)

Man weighing 154 pounds:
- Moderately active—2.7.
- Very active—3.3.
- Sedentary—2.2.

Woman weighing 123 pounds:
- Moderately active—2.2.
- Very active—2.7.
- Sedentary—1.8.

Pregnancy—2.5.
Lactation—3.0.
Children, under 1 year—0.6.
- 1–3 years—0.9.
- 4–6 years—1.2.
- 7–9 years—1.5.
- 10–12 years—1.8.

Girls, 13–15 years—2.0.
- 16–20 years—1.8.

Boys, 13–15 years—2.4.
- 16–20 years—3.0.

Nicotinic Acid
(Milligrams)

Man weighing 154 pounds:
- Moderately active—18.
- Very active—23.
- Sedentary—15.

Woman weighing 123 pounds:
- Moderately active—15.
- Very active—18.
- Sedentary—12.

Pregnancy—18.
Lactation—23.
Children, under 1 year—4.
- 1–3 years—6.
- 4–6 years—8.
- 7–9 years—10.
- 10–12 years—12.

Girls, 13–15 years—14.
- 16–20 years—12.

Boys, 13–15 years—16.
- 16–20 years—20.

Vitamin C
(Milligrams)

Man weighing 154 pounds—75.
Woman weighing 123 pounds—70.
Pregnancy (later half)—100.
Lactation—150.
Children, under 1 year—30.
- 1–3 years—35.
- 4–6 years—50.
- 7–9 years—60.
- 10–12 years—75.

Girls, 13–20 years—80.
Boys, 13–15 years—90.
- 16–20 years—100.

Vitamin D

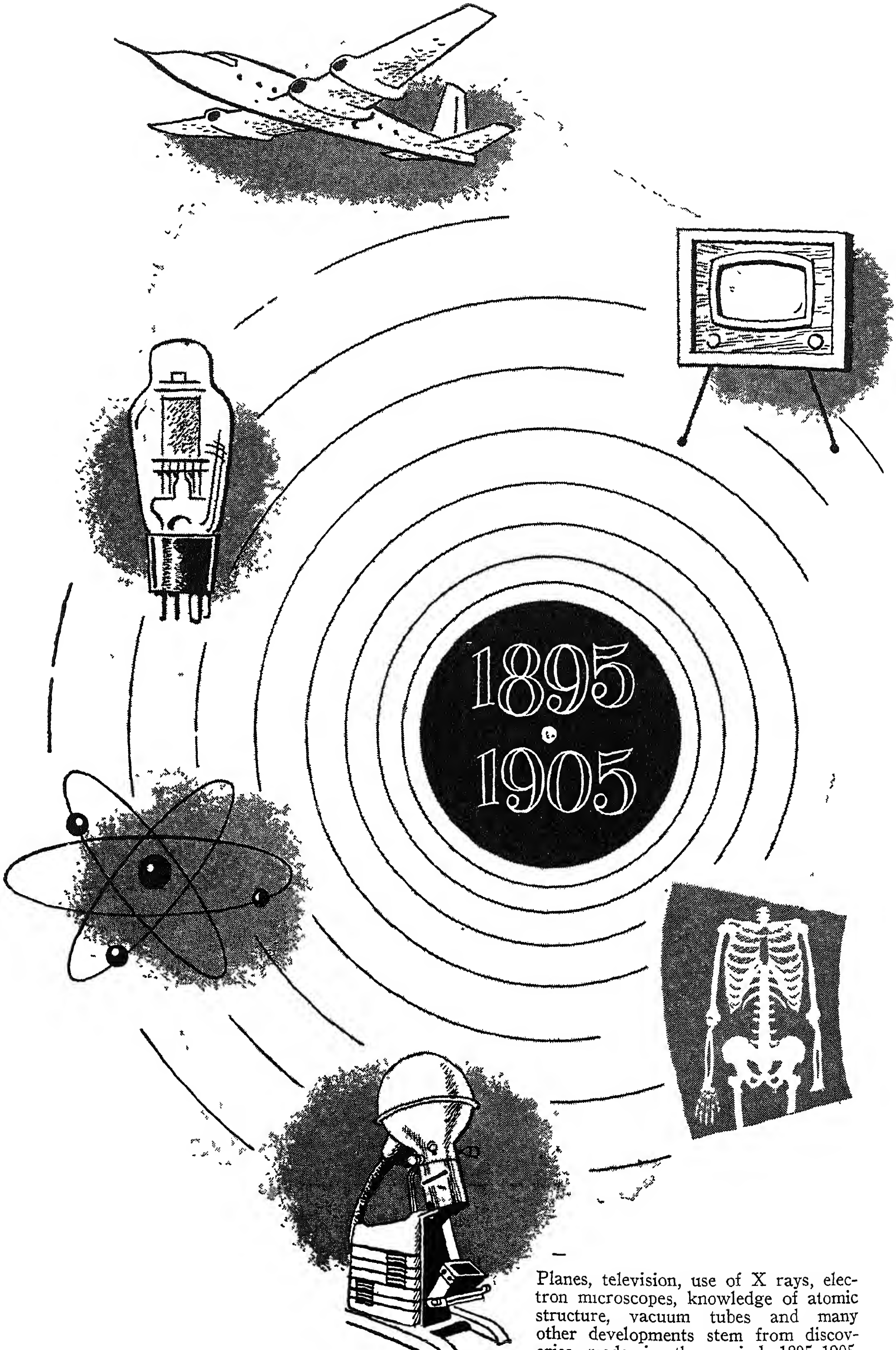
Pregnancy, lactation, and children under 1 year—400–800 international units.

Older children and adults also need it in similar amounts when it is not available from sunshine.

Dietary Allowances

At the National Nutrition Conference held in Washington in May, 1941, there was made public for the first time an important document entitled "Recommended Dietary Allowances." This has been popularly called a "dietary yardstick" because it was designed to serve as a guide in planning for adequate nutrition.

The need for such a yardstick had long been recognized and the task of formulating this table of dietary essentials was undertaken by the National Research Council's Committee on Food and Nutrition, headed by Russell M. Wilder, of the Mayo Clinic. Lydia Roberts, chairman of the Home Economics Department of the University of Chicago, heading a subcommittee assumed the responsibility of assembling opinions and data in support of the figures eventually submitted. Final approval of the Committee on Food and Nutrition was given on May 24, just before the National Nutrition Conference was held.



Planes, television, use of X rays, electron microscopes, knowledge of atomic structure, vacuum tubes and many other developments stem from discoveries made in the period 1895–1905

The Twentieth Century (1895-   ) I

by JUSTUS SCHIFFERES

THE ACHIEVEMENTS OF THE MIRACLE DECADE

SCIENCE dominates the twentieth century, carrying the world on its shoulders like the mythological giant Atlas. We are still debating whether it is to be our master or our slave — a Frankenstein monster or a good genie, bringing us a longer and a fuller life.

When did the ideas that rule our twentieth-century science come into being? It is difficult, of course, to set exact dates for scientific events. The birth of an idea and its proof or acceptance are often separated by years or even, as in the case of Copernicus, by centuries. However, we may with confidence place the birth of present-day science in the miracle decade that bracketed the turn of the century: the ten years from 1895, when Roentgen announced the discovery of X rays, to 1905, when Einstein published his special theory of relativity.

If all the new scientific facts that were discovered and the new scientific theories that were developed between 1895 and 1905 were wiped out, science in its present form simply would not exist. Twentieth-century scientific achievements are firmly rooted in that fateful decade. The developments of that period were the culmination of centuries of thought. But they came upon the scene with dramatic suddenness. Here are some of the developments of the miracle decade — theories, techniques, discoveries and inventions.

Physical sciences

- Aerodynamics — the building of the airplane.
- Astrophysics — the composition of the heavens.
- Atomic physics and nuclear chemistry — the new world of the atom.
- Electronics and "wireless telegraphy," or radio.
- Quantum theory — how "bullets of energy" act.
- Radioactivity; the discovery of radium.
- Relativity.
- X rays and vacuum tubes.

Biological sciences

- Biometrics (measurement of living things), biochemistry and biophysics.
- Bacteriological triumphs — the discovery of the infecting organisms of plague, syphilis and many other diseases.
- Genetics — reborn with the discovery of the "lost paper" of Mendel.
- Insect transmission of disease — "mosquitoes carry yellow jack."
- Psychoanalysis and Freudian psychology.
- Ultramicroscope.
- Viruses — infecting agents so small that they can pass through the finest filter.
- Vitamins.

The miracle decade saw the establishment of philanthropic foundations, like the Carnegie Corporation, and of industrial research laboratories, like that set up by General Electric at Schenectady, New York — developments that were to have a powerful effect on scientific research. In this decade, also, Nobel prizes in physics, chemistry and medicine and physiology were established. These awards, which were first granted in 1901, proved to be a stimulus to research men the world over; they also served to call the attention of the world at large to the achievements of science.

Just before the miracle decade, scientific and industrial progress seemed to have come to something of a standstill. The nineteenth century was resting on its laurels — it was viewing its wonderful accomplishments with smug pride or with gloomy forebodings. Scientists had become cautious; the resounding failure of Robert Koch's "cure" for tuberculosis, announced in 1890, served as a brake upon them. In biology Darwinism had spent its initial force. In the physical sciences, the end point of classical Newtonian physics seemed to be reached. "The future of physics is in the fifth decimal place," said the leading physicists. They meant that from then on physics would offer nothing more exciting than the tedious task of calculating physical constants (like specific heat) to greater degrees of accuracy. New developments were not expected in industry, either. The United States Commissioner of Labor reported that the "era of rapid industrial advance has ended for the civilized world, and the future of the great industrial countries offers no such opportunities as have the fifty preceding years for the creation of new tools and profitable employment." But all this was the lull before the storm.

To give some idea of the crowded happenings in the miracle decade, we are going to present them year by year. We are going to assume that the importance of each new discovery was *immediately apparent* so that it would make newspaper headlines. The headlines and the news items under them might then have read about as follows (our own comments are put in brackets):

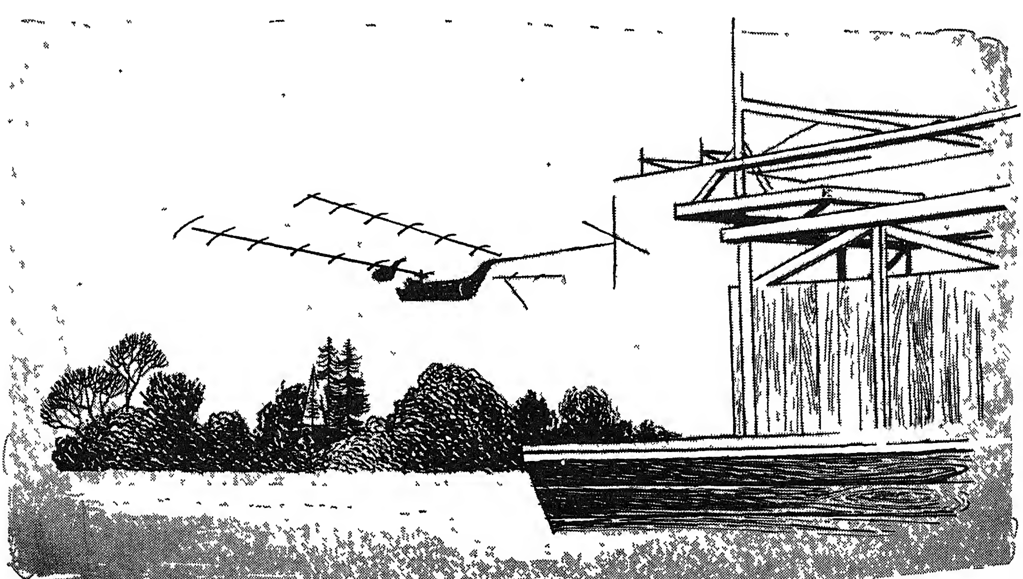
1895

X RAYS DISCOVERED

New Era in Physics Opens

Wuerzburg, Germany. — Wilhelm Konrad Roentgen announces the discovery of X rays. These rays — a hitherto unknown phenomenon — are produced in a vacuum tube and have the astounding property of passing through solid matter. Bones of the human body can be clearly revealed on photographic plates by sending X rays through the body. X rays will probably prove valuable in medicine and surgery.

On May 6, 1896, Samuel P. Langley launched a steam-driven model plane from a houseboat on the Potomac River This was the first sustained flight ever achieved by any mechanically propelled heavier-than-air craft.



French Embassy—
Information Division

ANTOINE-HENRI BECQUEREL

SUBCONSCIOUS MIND REVEALED
Sensational Development in Psychology

Vienna, Austria. — In their STUDIES IN HYSTERIA Sigmund Freud and Josef Breuer make the astonishing revelation that emotional reactions in human beings are largely controlled by "forgotten memories" repressed in the subconscious mind. People reveal their true opinions by slips of the tongue and in dreams. The authors tell how a young, well-educated girl, suffering from hysterical paralysis, was cured when she was made to realize her abnormal relationship to her father. [This was the beginning of psychoanalysis.]

1896

A MACHINE THAT FLIES
Steam-Driven Model Makes History

Quantico, Virginia, May 6. — Today marked a dramatic *first* in the history of aviation: a mechanically propelled heavier-than-air flying machine achieved sustained flight in the air. This machine was a nine-pound steam-driven model, constructed by Samuel P. Langley, secretary of the Smithsonian Institution of Washington. Langley launched the model from a houseboat on the Potomac River; it took the air at 3 05 P.M. and flew for half a mile under its own power. Photographs of the first flight were made by Alexander Graham Bell, inventor of the telephone. Mr. Langley, who is well known for his work on astronomy, has founded a new science of aerodynamics, which has its roots in the studies of birds in flight made by Leonardo da Vinci Langley began his work in Pittsburgh, where he invented a "whirling table" to study the effects of streams of air against an airfoil

TELEGRAPH WITHOUT WIRES
Messages Sent Two Miles

London, England. — Guglielmo Marconi, young Italian inventor, has sent wireless-telegraph messages for a distance of two miles through space. Marconi has set up his instruments in the London Post Office Building, with the permission and help of Sir William Preece, chief electrician to the Post Office. The brilliant young inventor expects ultimately to send communications by wireless across the Atlantic Ocean.

AN UNUSUAL PHOTOGRAPH
Peculiar Behavior of Uranium

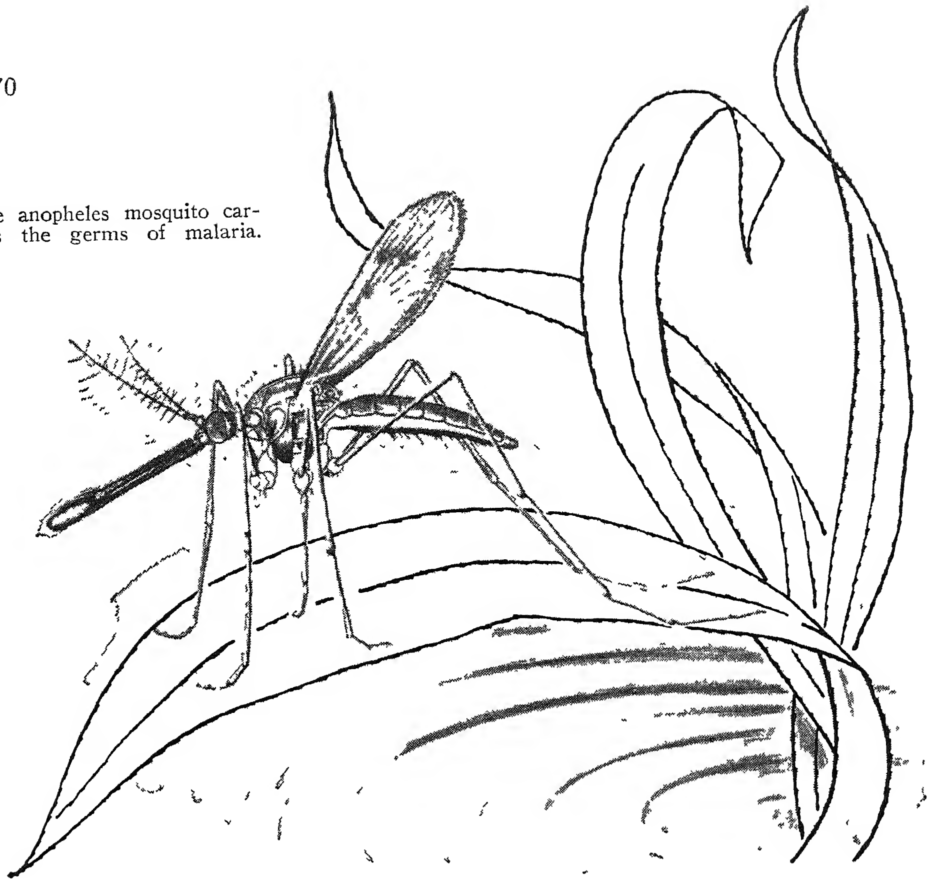
Paris, France. — Antoine-Henri Becquerel, professor of physics at the Polytechnic School in Paris, has called attention to the peculiar behavior of the chemical element uranium. He had left a photographic plate in a desk drawer with a key and a lump of uranium salt (the double sulfate of uranium and potassium). When he developed the plate, Becquerel found an image of the key on the photograph. Apparently uranium gives off something that acts like rays of light or X rays. [The peculiar behavior of uranium was due to radioactivity.]

1897

"CORPUSCLES OF ELECTRICITY"
Something New Inside the Atom

London, England, April 29. — Joseph John Thomson, professor of physics at Cambridge University, announced tonight, in a meeting at the Royal Institution, that

The anopheles mosquito carries the germs of malaria.



he had discovered a subatomic particle that he calls a "corpuscle of electricity." [This corpuscle corresponded to what is now called the electron; Thomson's discovery represented the starting point of the science of electronics.] Dr. Thomson has been working with electrical discharges through gases in vacuum tubes. Other physicists attending the meeting were openly skeptical.

A NEW FOOD FACTOR

A Cure for the Oriental Disease Beriberi

Batavia, Netherlands East Indies [now the Republic of Indonesia]. — Christiaan Eijkman, a Dutch army surgeon, reports a striking experiment. A crippling nervous disease resembling beriberi — a common ailment in the Orient — was produced in chickens and pigeons by feeding them only polished rice and was then cured by putting the birds on a diet of rice bran. The disease is apparently caused by the lack of an essential food factor [later called the antineuritic vitamin]. Here is the greatest new clue for the study and improvement of human nutrition since Beaumont's researches on the physiology of digestion. [A whole alphabet of vitamins was later to be discovered.]

1898

NEW ELEMENT DISCOVERED

Radioactivity within the Atom

Paris, France. — Pierre and Marie Curie announce the discovery of a new element, which they call radium because of its powerful radioactivity. It is said to be worth 100,000 times as much as gold. This young husband-and-wife scientific team has been following up Becquerel's work on the behavior of uranium; his findings gave the clue to the discovery of radium.

Radium is constantly disintegrating, giving off rays. This process, called radioactivity, is due to changes within the atom.

A NEW "LAZY GAS"

Striking Electric Effects Produced with Neon

London, England. — John William Strutt (Lord Rayleigh) announces the discovery of another inert, or "lazy" gas, called neon. [The previously known inert gases were helium, argon, krypton and xenon.] When an electric charge is passed through a glass tube filled with neon, the tube glows with a brilliant colored light, usually red. [This effect was later put to use in street signs.]

FILTERABLE VIRUSES

A Newly Discovered Cause of Disease

Berlin, Germany. — Friedrich Loeffler and Paul Frosch, of the staff of the Kaiser Friedrich Wilhelm Institute, have discovered disease-causing agents smaller than bacteria. On the borderline between the living and the dead worlds, they can pass through the finest porcelain laboratory filters; hence they have been called filterable viruses. They cannot be seen through an ordinary microscope. Loeffler and Frosch have demonstrated that certain viruses are responsible for hoof-and-mouth disease in cattle. They suspect that other viruses are the infective agents in a good many human diseases. [We now know that they cause yellow fever, rabies, dengue, infantile paralysis, measles and typhus fever in man. Certain plant diseases, like the mosaic disease of the tobacco plant, are also due to viruses. Iwanowsky called attention to these plant viruses in 1892.]

1899

INSECTS THAT CARRY DISEASE

Mosquitoes as Vectors of Malaria and Yellow Fever

Calcutta, India. — Major Ronald Ross, a surgeon in the British Army, who has been studying the life history of the malarial parasite, has proved that malaria can be transmitted to birds by the bite of an infected mosquito.

Rome, Italy. — Giovanni Battista Grassi, professor of comparative anatomy at the University of Rome, has demonstrated that the anopheles mosquito carries the germs of human malaria. Professor Grassi has been conducting experiments in various malaria-ridden spots in Italy.

1900

NEW INDICTMENT of the MOSQUITO

Reed Shows That One Species Carries Yellow Fever

Havana, Cuba. — Major Walter Reed, head of the United States Army Yellow Fever Commission in Cuba, reports that "the essential factor in infection . . . with yellow fever is the presence of mosquitoes that have bitten cases of yellow fever." Dr. Reed reached this conclusion following experiments "in the interests of science and for humanity" with United States Army volunteers. He was assisted in these experiments by Drs. James Carroll and Jesse William Lazear of the United States Army and the Cuban physicians Drs. Aristides Agramonte and Carlos Juan Finlay. Dr. Lazear died on September 25 of the effects of the disease that he was studying.

THE FOUR BLOOD TYPES

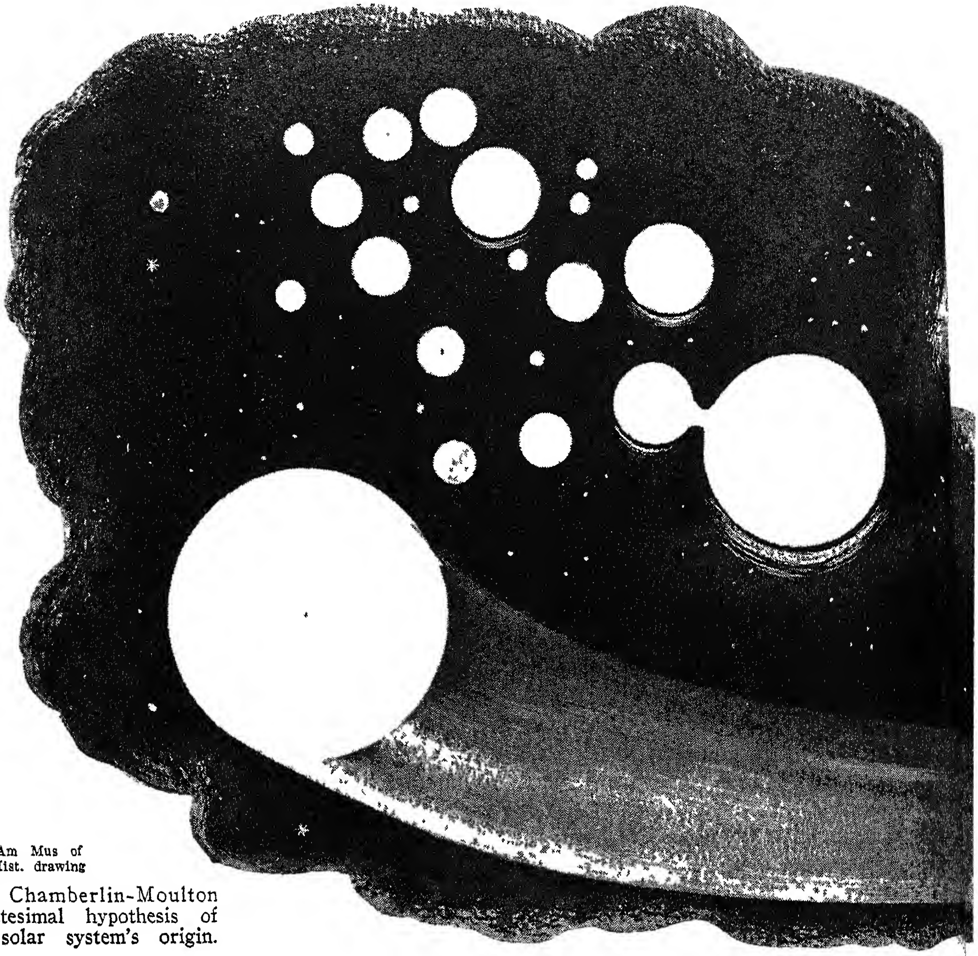
Blood Transfusion Made Safer

Vienna, Austria. — Karl Landsteiner, a young Austrian pathologist, reveals that there are four main types of human blood, which he labels A, B, AB and O. He finds that, in giving blood transfusions, if the blood of the donor belongs to the same type as the blood of the recipient, transfusion is safe and practical. Landsteiner's discovery will undoubtedly save many lives.

A MILESTONE IN GENETICS

The Rediscovery of Mendel's Lost Paper

Bruenn, Austria. — Gregor Mendel (1822–84), for many years Abbot of the monastery of Koeniginkloster, has at last come into his own. A 20,000-word paper by him, read before the Natural History Society of Bruenn in February and March 1865 and published in the proceedings of the society in 1866, has been rediscovered after being neglected for some thirty-five years. This paper represented a report on



From Am Mus of
Nat. Hist. drawing

The Chamberlin-Moulton planetesimal hypothesis of the solar system's origin.

the Abbot's experiments, extending over eight years, in the crossbreeding of common edible garden peas. The Austrian cleric had found the key to the riddle of heredity.

He introduced the ideas of dominant and recessive traits to help explain the subtly complicated course of heredity. He analyzed it on a mathematical basis, in terms of ratios. One of the fundamental Mendelian ratios is three to one — that is, in the generations bred from once-crossed hybrids, three out of four will display the dominant and one the recessive characteristic, whether it be length of stalk or color of hair.

Mendel's lost paper was rediscovered at about the same time in Holland, Germany, Austria and England. Among those who have revealed its importance are Hugo de Vries, the Dutch botanist who works with primroses and has observed mutations in the hereditary factors; the German biologist Karl Correns; the Austrian scientist Erich Tschermak; and the pioneer English geneticist William Bateson, who has translated Mendel's paper into English. Mendel's experiments are being repeated and verified all over the world. It is quite generally agreed that his system represents the greatest idea in biology since Darwin's theory of organic evolution.

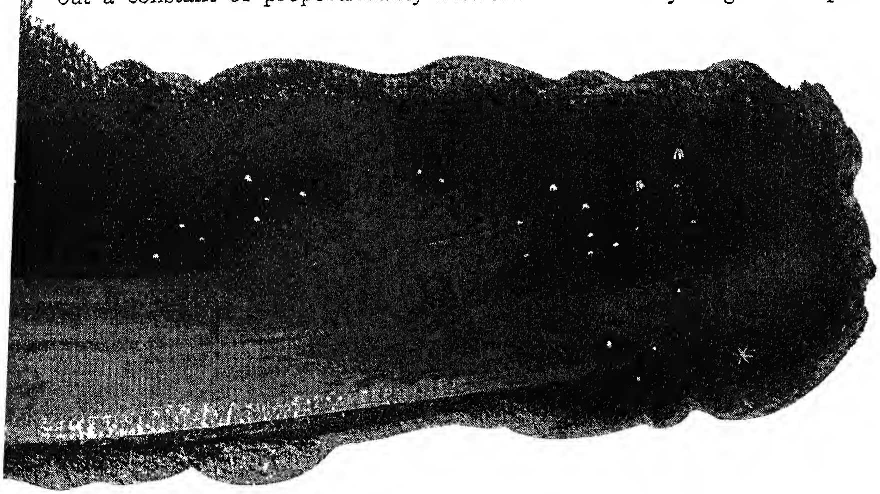
THE NEW QUANTUM THEORY

Does Energy Travel in "Bundles"?

Berlin, Germany, Dec. 14. — Max Planck, professor of physics at the University of Berlin, told the German Physical Society today that "radiant heat is not a continuous flow and indefinitely divisible." He said that "it must be defined as a discontinuous mass made up of units all of which are similar to one another."

Dr. Planck has been studying a beam

of radiation escaping through holes in a hollow body heated up to incandescence. He asserts that radiant energy does not flow out of the holes in the hot body continuously like a stream of water; on the contrary, he says, it is emitted in tiny "parcels," or "bundles" or "quanta," like bullets from a machine gun. These units are the smallest coin of energy that nature mints. To measure the energy contained in one quantum, Dr. Planck has worked out a constant of proportionality between



energy and frequency, called Planck's constant. [It later turned out that this constant holds good in the analysis of a great many different kinds of natural phenomena — for example, the photoelectric effects of light, the orbits of electrons in the atom, the wave lengths of lines in the spectrum, the frequency of X rays and the velocity with which gas molecules move.]

THE PLANETESIMAL HYPOTHESIS

A New Explanation of the Earth's Origin

Chicago, Illinois. — Two University of Chicago professors have a new theory of how our earth originated; they call it the planetesimal or spiral nebula hypothesis. These professors are the geologist Thomas C. Chamberlin, formerly President of the University of Wisconsin, and the astronomer-mathematician Forest Ray Moulton. They maintain that the earth and the other planets were formed by a number of little pieces of planet material ("planetesimals"), attracted to each other under the normal operation of the law of gravitation and growing in size like "snowballs in space."

MOTOR WAGONS

Another Use for the Horseless Carriage

St. Louis, Missouri. — The St. Louis POST-DISPATCH has ordered fourteen motor delivery wagons to speed its newspapers to all parts of the city. The first motor wagon ever built appeared this year on the streets of Denver, Colorado. This new version of the horseless carriage, hitherto used only for passenger travel, may replace the horse in time. Motor wagons come equipped with pneumatic tires, which the Goodrich Rubber Company first made for Alexander Winton's automobile in 1896. An automotive industry is rapidly growing up in Detroit.

THE NEW GENERAL ELECTRIC LABORATORY

A Commercial Firm Turns to Fundamental Research

Schenectady, New York, September 15. — For the first time a commercial firm — the General Electric Company — has opened a research laboratory devoted to fundamental scientific research without regard for practical results. The new laboratory is

CHARLES P. STEINMETZ

General Electric

located in a barn behind the home of the inventor Charles P. Steinmetz. Steinmetz, a mathematical wizard, who received his scientific training in Germany, has done a good deal of research in alternating electric currents. He has been a consulting engineer at General Electric since 1893.

1903

A MEMORABLE FLIGHT

A Man-Carrying Airplane Takes to the Air

Kitty Hawk, North Carolina, Dec. 17. — The brothers Wilbur and Orville Wright made several successful flights today in their man-carrying airplane. It marked the first time that a heavier-than-air flying machine carrying a human being took to the air, remained aloft for an appreciable period of time and then descended without mishap. The Wright brothers, who are in the bicycle business in Dayton, have done a good deal of experimenting with gliders.

NEW ULTRAMICROSCOPE

An Optical Instrument That Magnifies 2,500 Diameters

Jena, Germany. — Richard Zsigmondy, a colloid chemist, and Henry F. W. Siedentopf, chief of the microscopic division at the Zeiss glass works and professor of microscopy at the University of Jena, have invented a new microscope that will magnify objects up to 2,500 diameters. By using ultraviolet light, which has a shorter wave length than white light, and by immersing the microscope lenses in oil, they have made it possible to see worlds within worlds. It is believed that the new microscope, which is called the ultramicroscope, will be helpful in the study of genetics.

SLEEPING PILL AND PAIN-KILLER

New Triumphs for Organic Chemistry

Berlin, Germany. — Emil Fischer, one of Germany's foremost chemists, has created a new sleeping medicine and pain-killer, called veronal, or phenobarbital. [This was the first of a long line of pain-killing drugs — barbiturates — which can be made in the chemical laboratory.] Dr. Fischer has already produced synthetically a great many drugs and other substances that were formerly manufactured only by natural processes. He has synthesized simple sugars, caffeine — the active ingredient in coffee — and the purine derivatives of uric-acid compounds. His work is leading the way toward a whole host of substitute products of every type and description.

1904

A PRACTICAL USE FOR ELECTRONS

An Electron Tube for Wireless Telegraphy

London, England. — Sir John Ambrose Fleming, professor of electrical engineering at London's University College, has found a practical use for electrons. He has built an electron tube for use in wireless telegraphy. [This was the first step in the development of the vacuum tube used in electronic devices.]

Fleming's discovery is based on the so-called Edison effect, first observed and reported in 1883 by the distinguished American inventor Thomas Alva Edison. Experimenting with his newly invented electric light, Edison observed a glow inside the bulb as the carbon filament rapidly disintegrated. He then sealed a metal plate inside the tube. When the plate and the positive side of the supply circuit were connected, an electric current flowed through the vacuum tube *across space* from filament to plate.

Dr. Fleming has found a way to control the flow of electrons across space. His electron tube, or Fleming valve, will serve as a detector in wireless telegraphy.

1905

DISEASE GERMS ISOLATED

New Drugs Likely

Hamburg, Germany. — Fritz Schaudinn, zoologist at the Institute for Tropical Diseases in this city, has discovered the organism that causes syphilis (lues). This organism, called a spirochete, resembles a twisted thread and differs from ordinary bacteria. It is seen by reflected light in a dark-field microscope. This discovery rivals that of the trypanosomes, organisms that are the cause of African sleeping sickness and that are carried by the tsetse fly. Dr. Schaudinn has hunted out disease germs in the Arctic as well as the tropics; he went on an expedition to the Arctic Ocean in 1898.

The discovery of the syphilis spirochete caps a decade of discoveries of infecting organisms, including the causative agent of the bubonic plague and the germ that causes dysentery. Now that the organisms that cause these diseases are known, perhaps scientists will discover new drugs that will cure them. Is a new science of chemotherapy [curing by chemistry] in the offing?

THE NEW RELATIVITY THEORY

Einstein Solves the Riddle of the "Ether"

Zurich, Switzerland. — A clerk in the Swiss patent office, Albert Einstein, has published a paper in which he offers an explanation of the Michelson-Morley experiments. [These experiments, described previously, had cast in doubt the existence of the ether.] Einstein calls his explanation a "special theory of relativity." This theory makes it unnecessary to assume the existence of the ether or of all absolute notions of time and space; it calls for a fourth dimension, called space-time. If young Einstein is right, many of the doctrines of Newton must be modified.

These "news items" give some idea of the startling scientific developments of the miracle decade. In it was born a "higher physics" — more subtle than that of Galileo, Newton, Laplace, Faraday, Helmholtz and Maxwell. Today's physicists often deal with an absolutely unseen world, existing only in their imaginations. Facts concerning the invisible atoms, for example, can be accurately expressed only in mathematical equations. Pictures, models and diagrams of the atom are fanciful; they are useful enough for teaching purposes, but they correspond to nothing real. But, although the atom itself remains invisible, its predictable effects have been brilliantly analyzed.

New atomic concepts radically changed the nature of chemistry. In the past, chemical researchers kept collecting vast amounts of new data, which was duly stored in appropriate pigeonholes. But there were so many of these pigeonholes and, all too often, so little connection between them that chemists wallowed in a

mass of detail. Now, however, atomic theory has cast a flood of light on chemical relationships.

Other sciences, too, have made striking advances. In biology, new knowledge of the cell has led to many important discoveries in physiology and genetics; the use of radioactive tracer elements has proved a priceless tool in biological research. Anthropology and archaeology have thrown light on man's beginnings; psychology has traced the workings of the human mind. Medicine has continued the marvelous progress of the nineteenth century. It has provided new surgical techniques and lifesaving drugs; it has stressed, as never before, the effect of mind on body as a source of mankind's ills. Other sciences — astronomy, geology, meteorology, oceanography, among others — have also registered spectacular gains.

Not only in the field of theoretical science has the twentieth century distinguished itself. It has brought a host of technological improvements, which enable men to eat better, travel farther and faster, communicate more quickly and live longer and better than any previous generation in the long history of mankind. Unfortunately, advances in technology have not always been equally distributed throughout the world. Nor can all of them be classed as directly beneficial to mankind. New scientific weapons — poison gases, bombing planes, guided missiles, atom bombs and the like — have made war even more horrible to contemplate than before.

In the following chapters we shall have more to say about the fateful period extending from 1895 to 1905. We shall also trace the consequences of the discoveries made in the miracle decade.

THE ROAD TO MODERN ALCHEMY

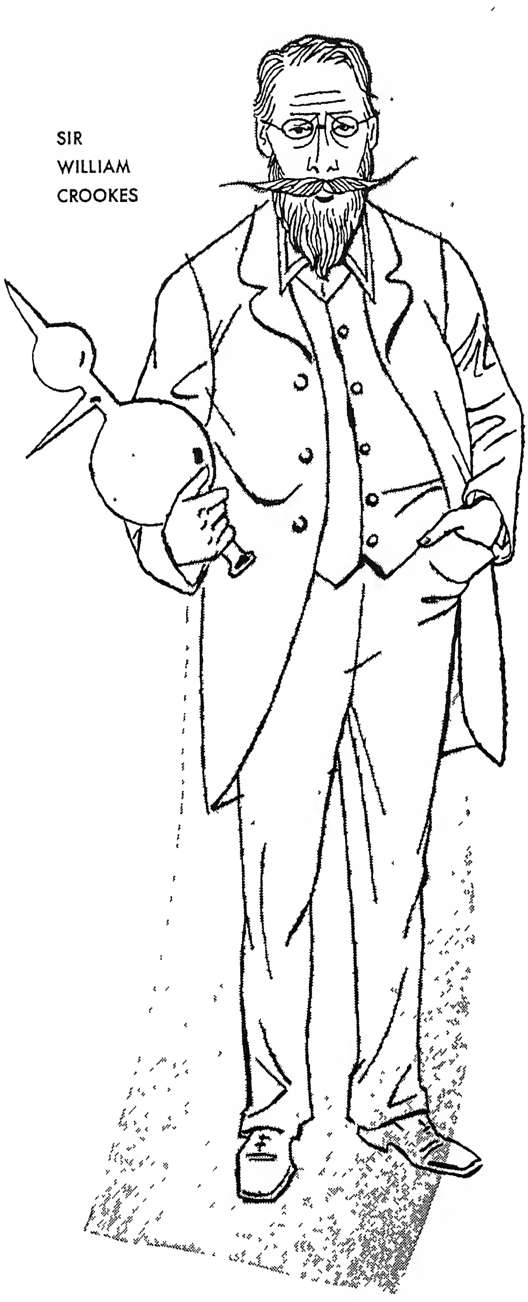
During the Middle Ages and long afterward, too, alchemists were eagerly trying to transmute, or transform, one metal into another — particularly, to change a base metal, like iron or lead, into a precious metal, like gold or silver. (See the chapter on the Middle Ages, in Volume 2.) Occasionally an alchemist would announce that he had succeeded in the quest; he would even display the "gold" that he had produced in his laboratory. But such claims always proved to be fraudulent.

By the nineteenth century, chemists and physicists had come to believe that it was impossible to transform one chemical element, like iron, into another chemical element, like gold. Each element, in its pure form, they held, was unchangeable. Its basic unit, the atom, was defined as the smallest possible particle existing in matter — a particle that could not be subdivided or altered in any way.

These concepts, which were held up to almost the end of the nineteenth century, have been abandoned by scientists. We now know that, far from being the smallest possible unit in nature, the atom is divided up into a number of subatomic (less-than-atom) particles. Furthermore, the atoms of one element can be changed into the atoms of another element by adding or subtracting subatomic particles. In the course of such transformations vast stores of energy are released. We have already succeeded in utilizing this energy in war (the atom bomb), and we are now seeking to apply it efficiently to the peacetime work of the world. Modern alchemy — the transmutation of the elements by man — represents an entirely new departure in science.

The history of modern alchemy goes back to the 1890's. It really begins with a complaint by an eminent man of science, Sir William Crookes (1832–1919). In the course of his career, Sir William discovered the chemical element thallium, studied the rare earths, produced diamonds artificially and undertook the scientific investigation of psychic phenomena. He accomplished much; yet he just missed making many discoveries that made other men famous.

Crookes was greatly interested in the study of electric discharges through gases, a field that had already attracted numerous



SIR WILLIAM CROOKES

investigators. A skillful German glass blower, Heinrich Geissler (1814–79), had succeeded in sealing wires, attached to metal electrodes, in glass tubes from which almost all the air had been evacuated — that is, vacuum tubes. He had found that when electricity was discharged in such tubes, a green glow was produced in the vicinity of the cathode, or negative electrode. Later investigators had concluded that the glow was caused by rays originating at the cathode — cathode rays, as the German physicist Eugen Goldstein (1850–1930) called them. Crookes developed an improved vacuum discharge tube, which was called the Crookes tube after his name. He performed many experiments with this apparatus and made a number of important discoveries about cathode rays.

Now we come to the noted scientist's complaint, which must have seemed quite unimportant at the time. The photographic plates that he was using in his laboratory in connection with his work were giving him a good deal of trouble; they often became fogged and did not give clear negatives. Crookes wrote to the manufacturers of the plates, pointing out their defects. The manufacturers apologized profusely, but they were not able to do anything about the plates, which continued to be fogged. Other scientists working with Crookes tubes noticed that their photographic plates were also being spoiled. For quite a while, however, nobody thought it worth while to investigate the matter.

The German physicist Wilhelm Konrad Roentgen (1845–1923) was the first to explain the phenomenon. While conducting a series of experiments with a Crookes tube in 1895, he made a momentous discovery. He noted that even when the tube was covered with black paper, through which no light could pass, a nearby sheet of paper coated with barium platinocyanide began to glow when electricity was passing through the tube. Evidently something that affected the coated paper was penetrating the black paper wrapped around the Crookes tube. Roentgen came to the conclusion that the phenomenon was due to some form of "penetrating rays." According to his own account, he called these rays X rays "for the sake of brevity." It is generally believed that he chose the letter X because it represents an unknown quantity in algebra.

Roentgen found that his X rays caused photographic plates to be fogged even when

the plates were wrapped in black paper. Apparently this paper, opaque to ordinary light rays, was transparent to X rays. That is why Crookes' photographic plates had been spoiled; they had been subjected to the X rays emitted by the discharge tubes in his laboratory

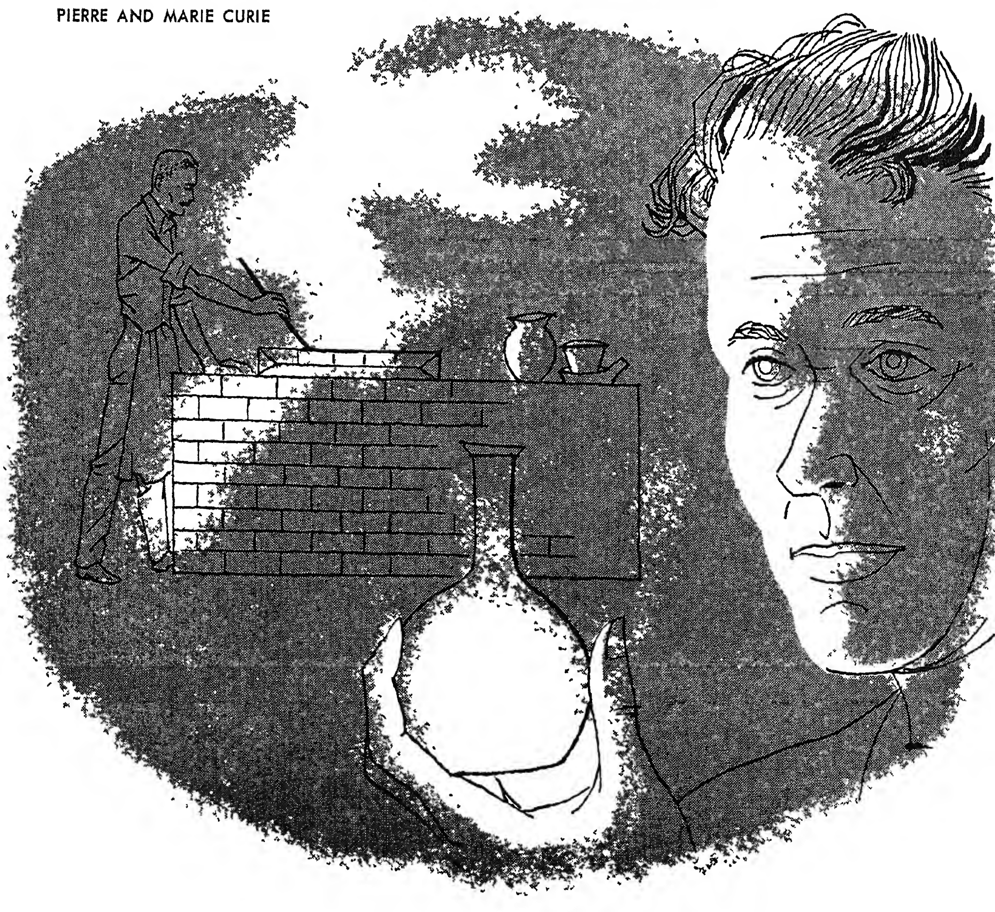
Roentgen had a man place his hand between a Crookes tube, in operation, and a photographic plate, and then he developed the plate. The internal structure of the hand was revealed, because the different parts of the hand were not equally penetrated by the rays.

Soon afterward a doctor in the United States used X rays to locate a bullet imbedded in a human body. Other physicians employed the rays to diagnose disease in the bones and to watch the growth of new bone after a fracture. In time X rays were used for a great many other purposes (see the article The Wonder-Working X Rays, in Volume 7). We now know that the rays are electromagnetic radiations, like light and radio waves.

The French physicist Antoine-Henri Becquerel (1852–1908) became interested in X rays after listening to a lecture on the subject given in 1896 by the mathematician Jules-Henri Poincaré (1854–1912) at the Academy of Sciences in Paris. In response to a question, Poincaré had remarked that X rays seemed to originate in the luminescent, or glowing, spot produced when cathode rays struck the glass of a discharge tube. Becquerel had long been interested in the luminescence of substances that glowed for a time in the dark after being exposed to a strong light. Among these substances was the uranium salt called potassium uranyl sulfate. When it glowed, was it giving off rays like the X rays discovered by Roentgen?

To find the answer to this question,

PIERRE AND MARIE CURIE



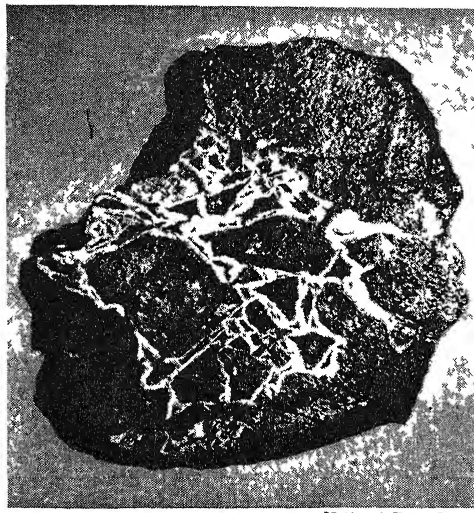
Becquerel wrapped a photographic plate in black paper, put a crystal of the uranium salt on top of the paper and then exposed the salt and paper to sunlight. When he developed the plate, he found that it had been darkened; this showed that the uranium salt emitted radiations that could penetrate paper. He later showed that these radiations could also pass through thin sheets of aluminum and copper.

Becquerel thought at first that the uranium salt had emitted the rays because it had been acted on by sunlight But he soon found that even when the salt was not exposed to light, it could affect a photographic plate. This unusual kind of radiation, which apparently arose spontaneously within a substance, represented something quite new in the experience of scientists. The name "Becquerel rays" was given to this phenomenon; later, as we shall see, it received the name "radioactivity."

The new radiations were next studied by perhaps the most remarkable husband-and-wife team in all the history of science —Pierre Curie (1859–1906) and Marie Curie (1867–1934). Pierre Curie, the son of a French physician, had distinguished himself by discovering the so-called piezoelectric effect produced by pressing upon a crystallized substance such as quartz. In 1895 he had been appointed to a professorship in the School of Physics and Chemistry at Paris.

A Polish girl, Marie (Marja, in Polish) Sklodowska was carrying on a series of experiments in the school. She had studied at the Sorbonne, living alone in an unheated garret, and had graduated with honors in physics and mathematics. After her graduation, she had begun to work on an industrial research job — a study of the magnetic properties of certain types of steel. She had begun this work at the Sorbonne, but the laboratory there was too crowded for comfort. That is why she had transferred her activities to the School of Physics and Chemistry.

The shy but distinguished professor and the brilliant young Polish girl fell in love and were married in the year 1895. Pierre continued with his own research



National Film Board

The mineral pitchblende yields radium

projects, while Marie began to study the radiations produced by compounds of uranium. She reported that all the uranium compounds she had examined were active; so were the compounds of thorium. She suggested the use of the word "radioactivity" to describe this particular kind of radiation.

While at work on various uranium ores, Marie noticed that the minerals pitchblende and chalcolite gave off more radiation than pure uranium itself She decided that these minerals must contain an element even more radioactive than uranium. Obviously the next step was to try to isolate the element. This project promised to be so fascinating that Pierre Curie gave up his own work in order to take part in research with his wife.

The Curies set out to isolate the radioactive agent in the pitchblende ore that was available to them. When they began to work on this ore, it was about two and a half times as active as uranium. After they had eliminated nonactive substances from the pitchblende one by one, they finally obtained a product whose radioactivity was something like four hundred times as great as that of uranium! They reached the obvious conclusion that the substance contained a hitherto unknown chemical element — a metal that they called polonium, after Marie Curie's native land (July 1898).

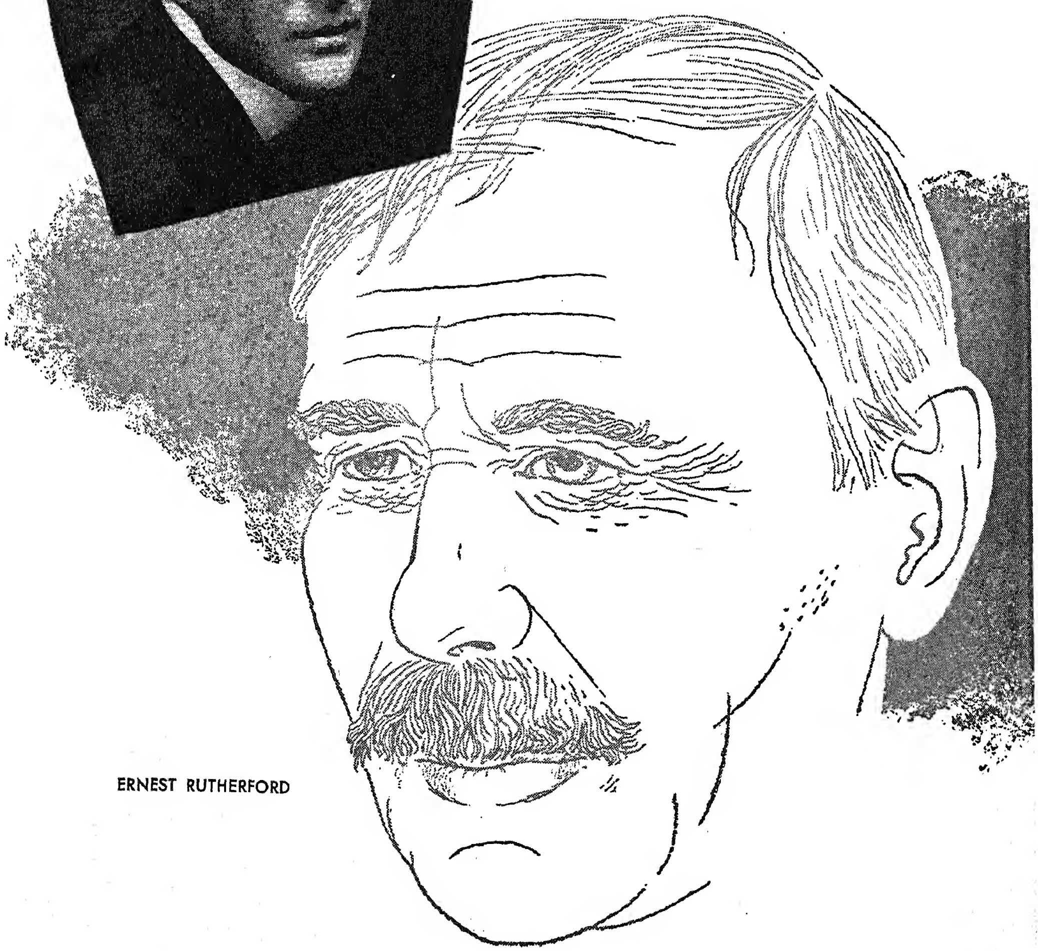
Continuing their investigation, the

Curies found that pitchblende contained still another radioactive substance, different from polonium in its chemical properties. They sought to isolate this substance and at last they obtained a product that was nine hundred times as active as uranium. This high radiation, they decided, was caused by still another new element, which they called radium, from the Latin *radius,* or ray (December 1898).

The radium-containing product that the Curies had prepared was not pure enough so that they could determine the atomic weight of radium or find out other essential facts about it. The next step was to extract from pitchblende a compound that would have more radium and less of other chemical elements. Through the cooperation of the Academy of Sciences in Vienna and the Austrian Government, the Curies obtained a ton of pitchblende ore, from which much of the uranium had been extracted. They now set to work to obtain, in as pure a form as possible, the tiny fraction of radium that it contained.

They worked under great difficulties in the old shed that served as their laboratory. Finally, after much back-breaking

Brown Brothers FREDERICK SODDY



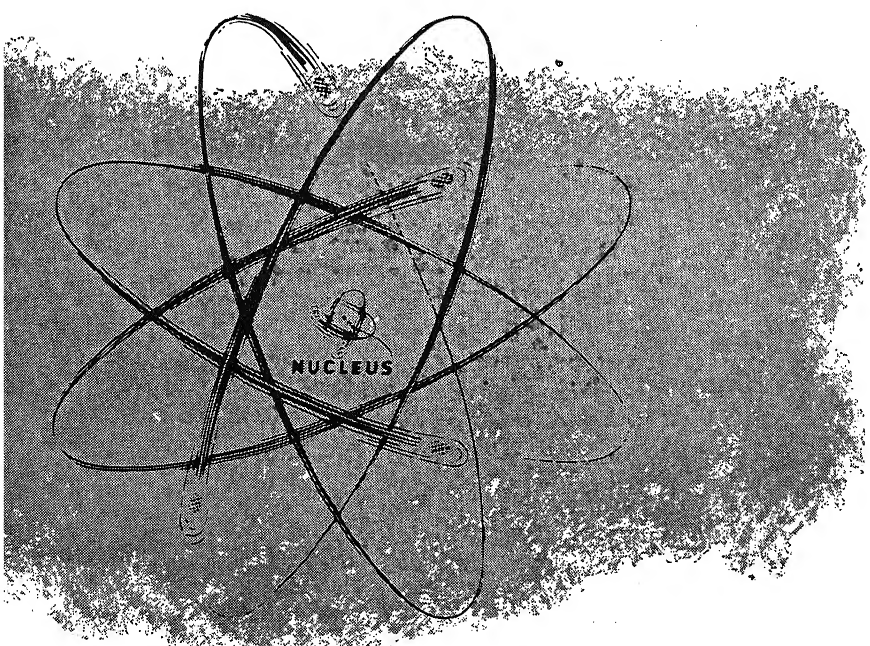
ERNEST RUTHERFORD

toil, they succeeded in extracting from the ton of pitchblende a tenth of a gram (less than four thousandths of an ounce!) of radium chloride, pure enough so that the atomic weight of radium could be determined (1902). The scientific world, which had been rather skeptical at first, now freely accepted the Curies' findings. In 1903 they received the Nobel Prize in physics (together with Becquerel) for their outstanding work.

The Curies had led an idyllic married life. A daughter, Irène (who was also destined to be a Nobel Prize winner) had been born in 1897; another daughter, Eve, in 1904. Everything was going well now. The Curies had a well-equipped laboratory to work in; Pierre had been named to a professorship at the Sorbonne. Then tragedy struck; on April 19, 1906, Pierre was run down by a heavy cart and instantly killed.

Bowed down by grief at first, Marie Curie carried on. She succeeded her husband as professor of general physics at the Sorbonne — the first woman to be so honored. She continued her scientific research, working particularly with radium and its compounds. Honors were showered upon her; among other things, she received a second Nobel Prize in 1911, the only person ever to win this award twice. She died in 1934 of pernicious anemia; the doctors who attended her said that she was "the eventual victim of the radioactive bodies that she and her husband discovered." She was only one of the long series of martyrs to science who died as a result of exposure to X rays and radium before it was recognized how dangerous these substances are when they are not shielded.

Marie Curie had insisted that radioactivity takes place within the atom itself. The New Zealand-born physicist Ernest Rutherford (1871–1937) and the English chemist Frederick Soddy (born in 1877) followed up this line of investigation. They worked together on the problem in the early 1900's at McGill University in Montreal, Canada, where Rutherford was professor of physics and Soddy a demonstrator in chemistry. In 1902 they pro-



The inner structure of a carbon atom. Six electrons are revolving around the nucleus.

Science Illustrated

posed a theory of radioactive disintegration, or decay. They stated that the atoms of radioactive elements undergo "spontaneous disintegration" and that as they do so they emit two kinds of particles — alpha particles and beta particles. Ultimately the atoms are transformed into the atoms of a new element.

Rutherford and Soddy pointed out that it is possible to measure the rate of decay for each radioactive element. This rate was determined in 1904 by Rutherford when he introduced the constant called the half life of radioactive elements. The half life of a radioactive element represents the time it takes for half its atoms to disintegrate — to be transformed into something else. If a given radioactive element has a half life of one minute, one half of its atoms will disintegrate in one minute; one half of the remaining atoms will have disintegrated by the end of the second minute and so on.

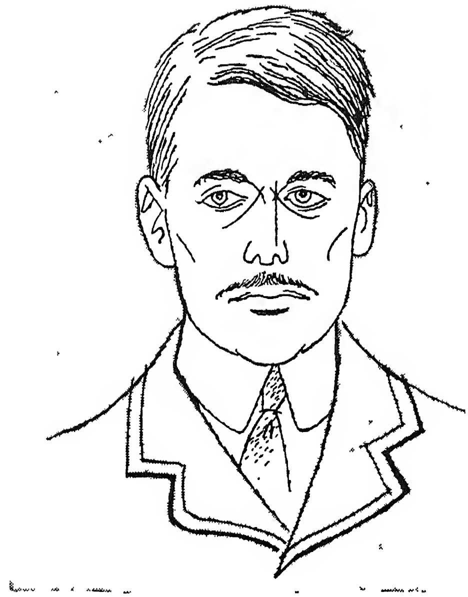
We now know that most radioactive elements found in nature radiate either alpha particles or beta particles; in a few cases both are emitted. In certain instances the alpha or beta rays are accompanied by a third kind of rays, called gamma rays. Alpha particles are really the nuclei of helium atoms; beta particles are electrons; gamma rays are electromagnetic radiations, like X rays.

Both Soddy and Rutherford went on to further scientific triumphs after their epoch-making report of 1902. Soddy received the Nobel Prize (in 1921) for his contributions to the discovery of isotopes; it was he who invented the word in 1913. Isotopes represent two or more forms of the same element; these forms occupy the same place (*isos* means "same" and *topos* means "place" in Greek) in the periodic table of the elements. Chemically, one isotope of a given element cannot be distinguished from the other isotopes of the same element. But isotopes differ from one another in atomic weight and sometimes also in radioactivity. By isolating the radioactive isotopes from the stable forms of an element, scientists have succeeded in producing atomic bombs. They have also produced tracer elements, which are used in medical, geological and botanical research. More than three hundred isotopes are found in nature.

Rutherford won a Nobel Prize (in 1908) for his work on the disintegration of elements. Later he became the first man to transform one chemical element into another. In 1919 he began bombarding nitrogen gas with alpha particles produced from radium. Now an alpha particle, as we have seen, is really the nucleus of a helium atom; its atomic weight is approximately 4. Rutherford found that a nitrogen nucleus, with atomic weight 14, would trap an alpha particle and would temporarily become an isotope of fluorine. Then the fluorine atom would break up into heavy oxygen (atomic weight 17) and hydrogen (atomic weight 1). In other words, Rutherford had made oxygen and hydrogen out of helium and nitrogen; he had changed one chemical element into another.

Rutherford was the first man, too, to try to picture the inner structure of the atom. It was clear by now that the atom was not the single and indivisible particle that nineteenth-century chemists had imagined. Certain atoms were known to emit various particles and to be changed thereafter into something else — that is, atoms of a different kind. In 1897 the English physicist Joseph John Thomson (1856–1940) had made the first effort to identify the actual composition of atoms. After experimenting with cathode rays, he came to the conclusion that atoms are made up of still smaller particles, negatively charged, which he called "corpuscles of electricity." These "corpuscles," which were later called electrons, were, according to Thomson, the ultimate particles of which all matter was composed. Later, scientists found that this idea was wrong, for other particles, positively charged, were also found in the atom. These positive particles (now known as protons) carry positive charges, equal in magnitude to the negative charges carried by the electrons.

At first, investigators had only the vaguest notion of how these negative and



HENRY G.-J. MOSELEY

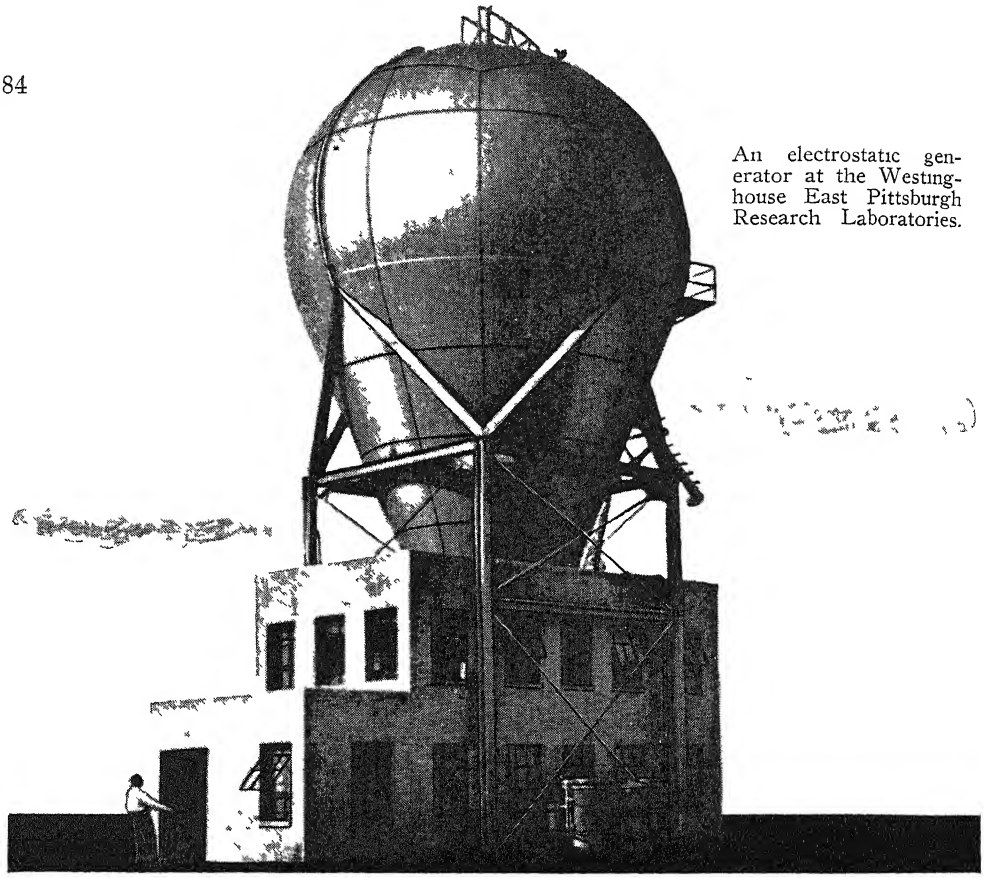
positive particles are arranged in the atom. In 1911 Rutherford developed a new and revolutionary theory about atomic structure. He thought of each atom as a kind of miniature solar system. There was a tiny core, or nucleus, made up of positively charged particles, at the center of the atom; this nucleus corresponded to the sun. Around the nucleus revolved the negatively charged electrons, like planets around the sun. According to this concept the atoms — even the atoms of heavy, normally solid elements like iron and copper and gold — consist chiefly of empty space, in which electrical particles ceaselessly whirl.

This picture of the inside of the atom — a miniature solar system of massed protons and orbital electrons — was modified somewhat by the Danish physicist Niels Bohr (born in 1885). He maintained that the electrons whirling around the nucleus of the atom are to be found in shells, suggesting somewhat the successive layers of the skin of an onion. Bohr also pointed out that the electrons give off energy when they jump from one shell to another. He explained many of the obscure events taking place inside the atom in terms of the accepted "classical" system of mechanics worked out by Kepler, Galileo and Newton.

In time it developed that the electron-shell theory could be used to explain the chemical reactions between different elements. It accounted for the firmness with which they grip each other, the speed with which they react with one another (as in explosions) and their failure to react (as in the case of the "lazy" gases, like neon, argon and helium). The chemical properties of the atom depend upon the number of electrons in its outermost shell. Different kinds of atoms are held together by bonds known as valence bonds. The electron theory of valence was worked out about 1916 by the American chemists Gilbert Newton Lewis (1875–1946) and Irving Langmuir (born in 1881).

How many electrons are whirling around the nucleus of the atom of a given element? This question was answered by the brilliant young English physicist Henry Gwyn-Jeffreys Moseley (1887–1915). Moseley, a pupil of Rutherford, measured the changes in the wave lengths of X rays as they were passed through the crystals of different chemical elements. He came to the conclusion that "there is in the atom a fundamental quantity which increases by regular steps as we pass from one element to the next. This quantity can only be the charge on the atomic nucleus . . . The number of charges increases from atom to atom by a single electronic unit . . . We are led by experiment to the view that . . . the number of charges is the same as the number of the place occupied by the element in the periodic system. This *atomic number* is, then, for hydrogen 1 [No. 1 in the periodic table], for helium 2 [No. 2 in the periodic table], for lithium 3 . . . for zinc 30, etc." The atomic number of a given element gives the number of electrons spinning around the nucleus. Thus hydrogen has one electron, helium 2, lithium 3 and zinc 30.

Moseley enlisted in the British Army in World War I and fell in battle in the disastrous Gallipoli campaign in 1915. Warned by his tragic fate, most of the warring countries in World War II did not allow their promising scientists to enlist for front-line war service.



An electrostatic generator at the Westinghouse East Pittsburgh Research Laboratories.

A colleague of Rutherford, Francis W. Aston (1877–1945), turned his attention to the study of isotopes. How could one separate the different isotopes of a given element from one another? Aston suggested that this might be done by (1) evaporation, since the lighter atoms would escape from a liquid faster than the heavier ones; (2) by the diffusion of a gas through a porous clay barrier; (3) by electromagnetic separation. He used all three methods in separating isotopes.

To bring about the electromagnetic separation of isotopes, Aston was forced to invent a new and, as it turned out, a very important, scientific instrument, called the mass spectrograph. This consists of a tube that produces beams of positive ions (electrified particles) and a magnet that curves the beams. The lighter isotopes are curved more than the heavier ones; hence, each isotope will form its own pile. The piles can be made to fall on photographic plates, where they can be studied.

In 1932 Professor Harold Clayton Urey (born in 1893) of Columbia University made an important discovery by using the mass spectrograph. Working with Ferdinand G. Brickwedde and George M. Murphy, he isolated the hydrogen isotope known as heavy hydrogen. A gallon of liquid hydrogen, prepared by the United States Bureau of Standards, was allowed to evaporate away until only a fraction of an ounce was left. The experimenters then examined the residue in a mass spectrograph. On their photographic plates, they found a spot corresponding to a pile of isotopes with atomic weight 2. (The ordinary hydrogen atom has atomic weight 1.) When heavy hydrogen is combined with oxygen, it makes "heavy water," which has proved to be very useful in biological studies.

In the early 1930's, atomic researchers were faced with a vexing problem. It was agreed that the nucleus is made up of positively charged protons and that as

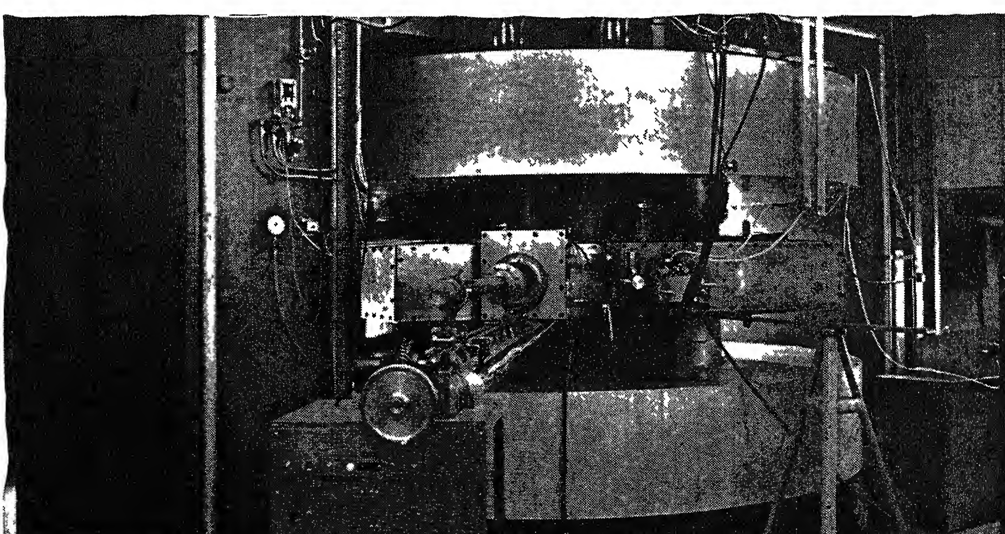
many negatively charged electrons whirl around them in different shells, or orbits. Now the weight of the atom is almost entirely in the nucleus, since an electron is about 1/1838 as heavy as a proton. As each proton has the same weight, the atomic weight of a given element should correspond to the number of protons. The nucleus of hydrogen, the lightest element, contains one proton and its atomic weight is approximately 1. If the nucleus consisted entirely of protons, helium, with 2 protons, should have atomic weight 2; iodine, with 53 protons, should have atomic weight 53; uranium, with 92 protons, should have atomic weight 92.

But what do we find? The atomic weight of helium is 4; of iodine, 127; of uranium, 238. Apparently there must be some other particles in the nucleus to account for the proportionately greater atomic weight of the heavier atoms. In 1932 James Chadwick (born in 1891), another pupil of Rutherford, solved the mystery. He demonstrated that the nucleus of the atom contains, in addition to positively charged protons, neutral particles, which have the same mass as the protons but no electric charge. (The ordinary hydrogen atom is the only one that contains no neutral particles.) Chadwick gave the neutral particles the name of "neutrons."

The sum of the weights of the protons and neutrons in the nucleus gives the atomic weight of a given atom. There is one proton and no neutron in the hydrogen atom; it has atomic weight 1. There are 8 protons and 8 neutrons in oxygen; it has atomic weight 16. There are 92 protons and 146 neutrons in the uranium atom; the atomic weight of uranium is 238.

We saw that Rutherford had bombarded nitrogen atoms with alpha particles from radium as atomic bullets and that the end products were oxygen and hydrogen. Alpha particles travel at the speed of some 18,000 miles a second; but they are not nearly fast enough or powerful enough to serve as really effective atomic bullets. In 1932, Drs. J. D. Cockcroft and E. T. S. Walton, working in Rutherford's laboratory, pointed the way to bigger and better atomic bombardments: they designed high-voltage electric generators and vacuum tubes that could withstand such high voltages. With apparatus yielding an output of almost 800,000 electron volts, they transformed lithium and hydrogen into helium, releasing energy in the process.

Even bigger atom-smashers were constructed in the United States. Dr. Robert J. Van de Graaff (born in 1901), working



McGill University

Cyclotron at McGill University, Montreal, Quebec.

first at Princeton and later at the Massachusetts Institute of Technology, designed the electrostatic generator that is pictured and described on page 1433. The first Van de Graaff electrostatic generator, constructed in 1931, had an output of 1,500,000 electron volts. In later models this voltage was increased many fold.

At the University of California Dr. Ernest O. Lawrence (born in 1901) constructed a new kind of atom-smasher, called a cyclotron. The principal feature of the cyclotron is a huge electromagnet that keeps whirling atomic bullets (electrons, or protons, or neutrons or atomic nuclei) round and round until they gain tremendous speed and voltage. The original model, built in 1931, produced protons with an energy of 80,000 electron volts; later models were more than 2,000 times more powerful. A diagram of the cyclotron is shown on page 1434.

With such powerful atom-smashers, scientists were able to perform fresh miracles. They broke the atom into its parts; they converted one atom into another. Two young French scientists — the husband-and-wife team of Irène Joliot-Curie (born in 1897) and Frédéric Joliot-Curie (born in 1900) — even succeeded in creating artificial isotopes. Mme. Joliot-Curie was the older daughter of Pierre and Marie Curie; M. Joliot-Curie, whose family name was Joliot before his marriage, had been one of Marie's students at the Sorbonne. Ever since their marriage, in 1926, the two young scientists had worked together on the problem of radioactivity.

In 1934, they bombarded aluminum atoms, using alpha particles as atomic bullets. The end product was a hitherto unknown isotope of phosphorus. It gave off gamma rays, thus showing that it was radioactive; then in the brief space of fifteen minutes it disappeared and all that was left in the experimenters' test tube was silicon. The Joliots had created the first artificial radioactive isotope; in 1935 they received the Nobel Prize for their accomplishment. (In later years their unquestioning acceptance of communist doctrines laid them open to justified criticism.) Today radioactive isotopes are produced in quantity in nuclear reactors, or atomic piles; they are used extensively in medical and biological research.

The transmutation of elements under bombardment by atomic bullets went merrily on. Another era of alchemy was at hand — the "newer alchemy," as Rutherford called it. (That, incidentally was the title of his last book, published in 1937.) Finally the dream of the old alchemists — the transmutation of a base metal into gold — was achieved. In 1941 Dr. Kenneth T. Bainbridge of Harvard University and an associate, using a late-model atom-smasher, succeeded in converting mercury into gold. This achievement created little excitement, since the amount of gold obtained in this way was exceedingly small and the cost of producing it was great. It would have been more profitable, from a commercial standpoint, to dig for gold in the ground or even to buy it in the open market!

Thus far the transmutation of atoms had taken place only in the laboratories of scientists, and it had had no particular effect upon the world at large. But now certain researchers turned to a new approach, which was destined to have the most momentous results for all mankind. Scientists had known for some time that if a heavy atom like that of uranium (atomic weight 238) could be completely broken up, an enormous amount of energy would be liberated. Even if this atom could be split in two, the amount of energy released would still be fantastically great. Might not this energy provide explosives of terrifying effectiveness?

The lowering clouds of war in the late 1930's and the actual outbreak of World War II in 1939 lent a new and terrible urgency to this question. Soon the scientists of nazi Germany and of certain Allied powers (particularly the United States, Great Britain and Canada) were secretly engaged in a life-and-death race to develop an atomic bomb, which would derive its titanic power from the smashing of heavy atoms. In a later chapter we shall see what came of this race.

SCIENCE THROUGH THE AGES is continued on page 3407.